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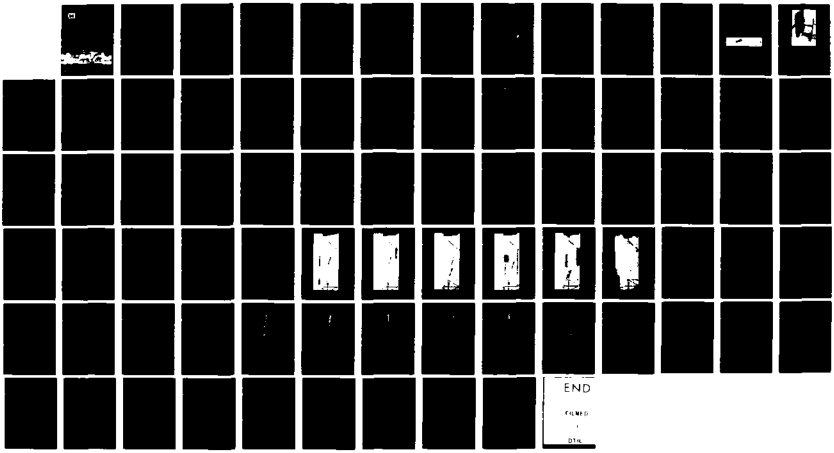

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TECHNICAL REPORT HL-82-23

McGEE CREEK PUMPING STATION SIPHON PIKE COUNTY, ILLINOIS

Hydraulic Model Investigation

by

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Final Report

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A 1:4.36-scale hydraulic model of the proposed McGee Creek pumping station siphon was used to develop a design with adequate hydraulic performance. The saxophone outlet design was modified to ensure maintenance of the priming seal. Priming times and head losses were measured in the model. Modifications to decrease priming times were tested, including a reduced cross-sectional area at the crown, and air escape vents. The recommended design siphon operated satisfactorily for the entire range of expected tailwaters and discharges.

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PREFACE

The model investigation of the McGee Creek pumping station siphon reported herein was authorized by the U. S. Army Engineer District, St. Louis (LMS), on 13 January 1981.

This investigation was conducted during the period January 1981 to January 1982 in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES), under the direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, and Mr. J. L. Grace, Jr., Chief of the Hydraulics Structures Division, and under the general supervision of Mr. N. R. Oswalt, Chief of the Spillways and Channels Branch. The project engineer for the model study was Mr. R. R. Copeland, assisted by Mr. E. L. Jefferson. Mr. E. B. Williams is acknowledged for his work in constructing the model. This report was prepared by Mr. Copeland.

During the course of the study, Messrs. James Luther, Walter Wagner, and Ben Venturella of LMS; Emil Cook and Mark Wagner from the consulting firm of Crawford, Murphy and Tilly, Inc.; Joe McCormick, Larry Eckenrod, Larry Cook, and Roddis C. Randall of the Lower Mississippi Valley Division; and John S. Robertson of the Office, Chief of Engineers, visited WES to discuss the program of model tests, observe the model in operation, and correlate test results with concurrent design work.

Commanders and Directors of WES during the conduct of this investigation and the preparation and publication of this report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	0.4047	hectares
cubic feet per second	0.02831685	cubic metres per second
Fahrenheit degrees	*	Celsius degrees or Kelvins
feet	0.3048	metres
feet of water	0.03048	kilograms per square centimetre
feet per second	0.3048	metres per second
inches	25.4	millimetres
miles (U. S. statute)	1.609344	kilometres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

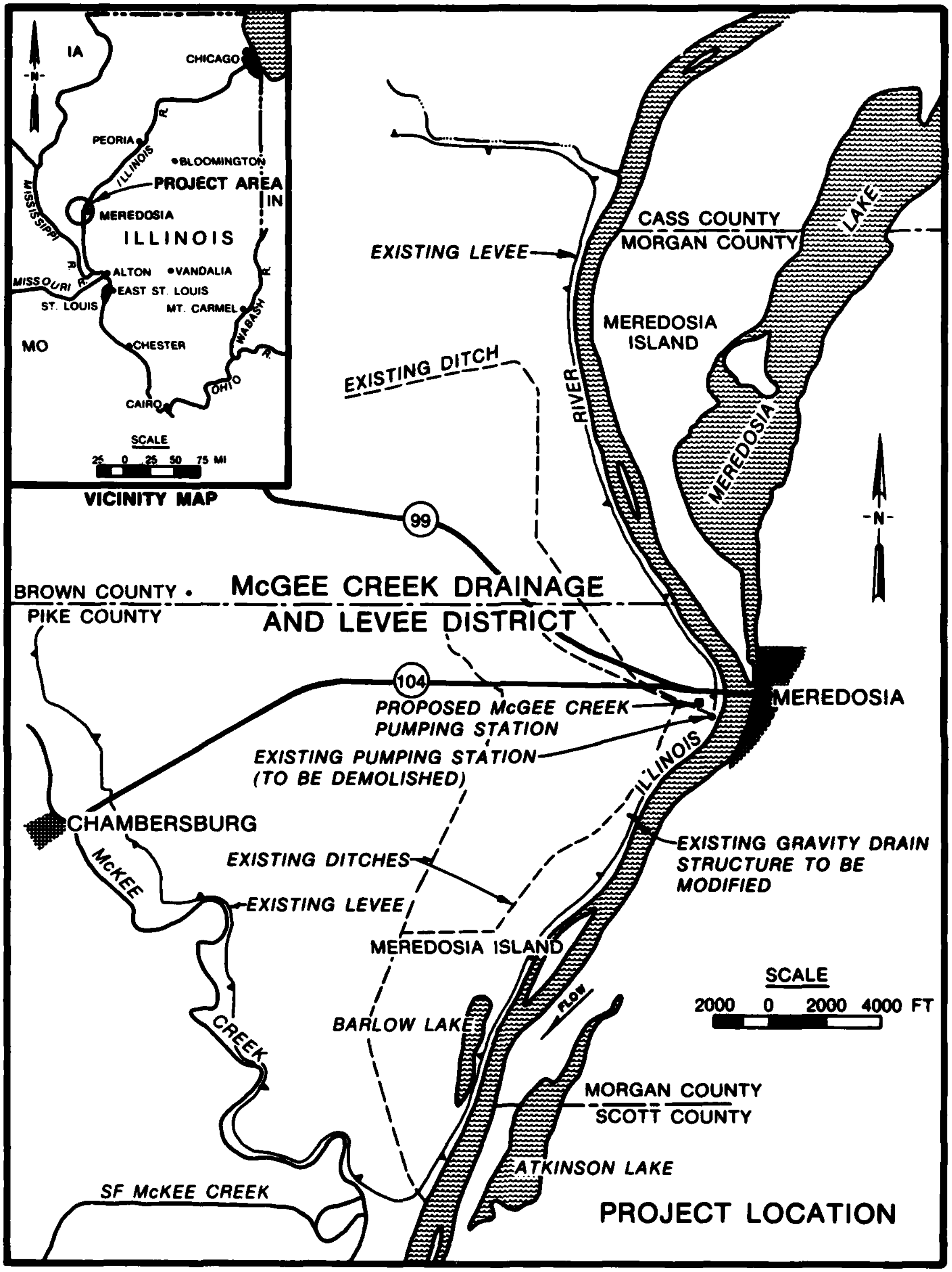

Figure 1. Location map

McGEE CREEK PUMPING STATION SIPHON

PIKE COUNTY, ILLINOIS

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. The proposed McGee Creek pumping station is to be located in west central Illinois, in the northeast corner of Pike County. The site is located on the west bank of the Illinois River about 1 mile* west of Meredosia, Illinois, and about 52 miles west of Springfield, Illinois (Figure 1). The pumping station is part of a flood-control project that will provide protection to approximately 12,200 acres of predominantly agricultural lands in the McGee Creek Drainage and Levee District.

2. An existing pumping station and gravity-flow structure currently provide limited flood protection to the McGee Creek Drainage and Levee District. These structures cannot maintain a sufficiently low groundwater elevation during the growing season due to seepage through the Illinois River levee and rainfall runoff. Overbank flood damages begin at el 422.7,** and high water-table damages to crops begin at el 420.7. The existing pumping station has a capacity of 196 cfs and has maintained a mean annual flood elevation of 424.2 over a 40-year period of record. The gravity-flow drain is essentially useless, except during winter months when water levels in the ditches are allowed to rise above those maintained during the growing season. The existing station will be demolished after completion of the new pumping station.

3. The proposed pumping station will have three vertical

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

** All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

propeller-type mixed or axial flow pumps operating with siphonic recovery. Design discharge for each pump at high operating heads is 107 cfs; at a low operating head, the expected discharge for each pump is 133 cfs. Minimum priming discharge is 89 cfs. Discharges will vary depending on the operating head and the pump characteristics. The first pump will be started when the water level in the sump reaches el 419.5, the second at el 420.5, and the third at el 421.5. Pumps will be shut off with sump water surfaces at el 420.5, 419.5, and 418.0. The proposed pumping station would maintain a mean annual flood elevation of 420.9. The mean number of pumping days required annually would be reduced from 153 to 67, and the mean number of days requiring full pumping capacity would be reduced from 95 to 23 days annually.

4. Three 48-in.-diam steel discharge pipes will convey flow from the pumping station, over the levee, and into the outlet structure and Illinois River. The inside of the pipes will be coated with coal-tar epoxy enamel. An air vent will be located at the crown or summit of the siphon. The vent will be opened to relieve positive pressures that accompany pump start-up and then will be closed to initiate priming. When the pumping operation is completed, the air vent will be opened to break the siphon and prevent backflow. At the outlet, in order to provide a priming seal, the discharge pipe will be turned upward like the bell of a saxophone--hence the name saxophone outlet. Elevation of the outlet determines the maximum negative pressure that will occur in the primed siphon. Negative pressures in excess of 28 ft of water may cause cavitation or result in excess leakage at pipe joints. The adverse slope of the saxophone outlet will direct flow upward. Energy of the efflux will be dissipated on a concrete capstone and riprap-bedded outlet channel. Tailwaters in the outlet channel will range between el 419.0 and 449.5.

Purpose of the Model Study

5. Design guidance for pumping station siphons is generally lacking. Pumping station siphons differ from siphon spillways (which are capable of rapid increases in discharge and for which there is

considerable design guidance) in that discharge of pumping station siphons is limited by the relatively constant capacity of the pump. This makes it essential that the siphon prime with the minimum discharge capacity of the pump and that "washout" be prevented with the maximum discharge capacity of the pump prior to priming. Also, friction losses are typically more important in pumping station siphons and form losses are more important in siphon spillways. Problems with priming pumping station siphons may be due to insufficient air entrainment, inability to transport the entrained air out of the siphon, and/or washout of the priming seal.

6. The original siphon design was analyzed by engineers of the Hydraulic Structures Division at the U. S. Army Engineer Waterways Experiment Station (WES). Preliminary calculations (with an unsubmerged outlet and the maximum discharge expected at the start of priming) indicated that the hydrostatic head provided by the saxophone outlet would be insufficient to resist the momentum forces of the supercritical flow coming down the riverward leg of the discharge pipe. Therefore, a hydraulic jump could not form in the discharge pipe and there would be no priming seal. Without siphonic head recovery, the pumps proposed for the McGee Creek pumping station would be unable to deliver the design discharge. The model investigation was therefore recommended and conducted to study the hydraulic characteristics of the siphon and to develop a satisfactory design of siphon that will ensure maintenance of the priming seal and adequate priming characteristics.

PART II: THE MODEL

Description

7. The McGee Creek pumping station siphon was modeled at an undistorted linear scale of 1:4.36. The entire 397-ft-long siphon was simulated from the prototype pump location to the saxophone outlet. The model was constructed of transparent plastic pipe so that hydraulic flow conditions could be observed. Air vents located on the siphon crown were also simulated. The saxophone outlet discharged into a tailbay of sufficient height to allow testing with the full range of expected tailwaters. The tailbay had a large window so that flow conditions in the saxophone outlet could be observed. Flow through the model was recirculated by centrifugal pumps. Discharge was measured with a paddle-wheel flowmeter and displayed electronically. Flow rates were controlled by an automatic valve. An overall view of the model is shown in Figure 2.

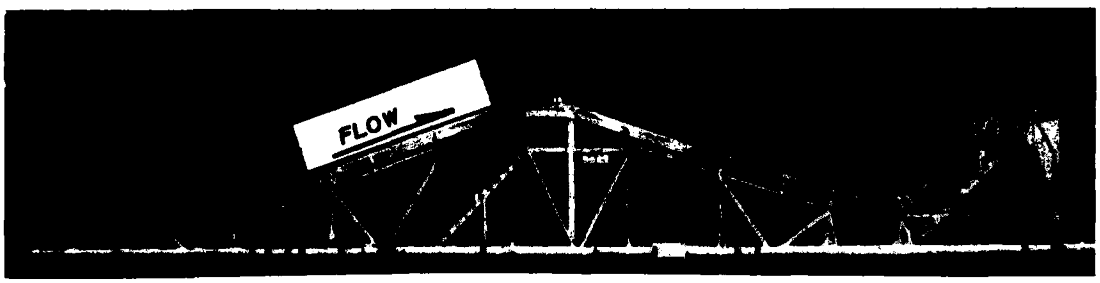

Figure 2. 1:4.36-scale model of pumping station siphon

8. Hydrostatic pressures were measured at 48 locations in the model with piezometers and at one location with an electronic pressure cell mounted flush with the bottom of the pipe. Locations of the piezometers are shown in Plate 1; the piezometer board and control panel are shown in Figure 3. At each piezometer station, two taps were made in the pipe. On the landward (upstream) portion of the siphon, these taps were placed on each side of the pipe at middepth. On the riverward (downstream) portion of the siphon, the taps were placed 45 deg from the vertical center line in the bottom quadrants of the pipe. The two

Figure 3. Model piezometer board and control panel

piezometer taps at each station were connected so that the reading represented an average pressure. The electronic pressure cell was located at sta 0+63 which was far enough downstream from the prototype pump location to avoid any significant flow disturbances that were introduced by the 90-deg flow curvature entering the siphon. The pressure cell was used to measure instantaneous pressure fluctuations due to hydraulic forces that would be expected to occur at the prototype pump location. In the model investigation of the Pointe Coupee pumping station siphon conducted by WES (Copeland 1982), it was determined that pressure

fluctuations due to vibration of the model's pumps and the model itself had a much higher frequency than the pressure fluctuations due to hydraulic forces. The high-frequency fluctuations were filtered electronically so that only the frequency fluctuations related to hydraulic forces were recorded. The piezometers were used to measure the average hydrostatic pressure and the electronic pressure cell was used to measure instantaneous pressure fluctuations.

9. Air flowed into the siphon through one of the air vents at the siphon crown and airflow was measured with a hot-wire anemometer. The air vent diameters were geometrically similar to those in the prototype. The air vent was extended sufficiently to ensure uniform velocity distribution at the point of velocity measurement.

Interpretation of Model Results

10. The principle of dynamic similarity, which requires that the ratios of forces be the same in the model and prototype, is the basis for the design of models and the interpretation of results. The hydraulic performance of a siphon is affected by inertial forces (forces resulting from changes in the magnitude or direction of the velocity), gravitational forces, viscous forces, and surface tension. It was not practical, in this case, to conduct a model investigation in which all of the forces influencing flow were scaled correctly. However, during certain operating conditions when fundamental flow characteristics are the same in the model and prototype systems, the differences in force ratios are negligible or can be accounted for by calculating adjustments to the model results. For other operating conditions, these forces are not negligible and only qualitative model results are possible. Qualitative model investigations are useful in evaluating the merits of one design against another. Hydraulic conditions of primary interest in this model study are influenced predominantly by gravitational and inertial forces; therefore, the model was constructed and operated based on the Froudian criteria.

11. When the siphon is flowing full (after being primed), the forces influencing hydraulic performance are gravity, viscosity, and

inertia. It is the gravitational and inertial forces that predominate at the outlet where flow is discharged into the outlet channel and the viscous and inertial forces that predominate in the pipe itself. It has been established by several investigators involved in siphon model studies (Gibson, Aspey, and Tattersall 1931; Whittington and Ali 1972) and is generally accepted (Naylor 1935; CBIP 1956; Babb, Amoracho, and Dean 1967; Head 1975) that if the Reynolds number of flow in the model exceeds 1.8×10^5, then in cases where friction is negligible, the viscous scale effects will be negligible. When friction losses are not negligible, adjustments to the model or to the model results can be made to account for scale effects due to friction. Thus, if the model is constructed large enough so that the Reynold's number of flow exceeds 1.8×10^5, then viscous effects are insignificant and the Froudian criteria may be applied. The Reynolds number of flow ranged between 1.8×10^5 and 7.9×10^5 in the McGee Creek siphon model tests.

12. When the siphon is flowing partially full (with the air vent at the crown open or during priming), hydraulic performance is influenced by the forces of gravity, viscosity, inertia, and surface tension. The process of air entrainment by the hydraulic jump has been shown to be primarily a function of the Froude number and pipe slope (Kalinske and Robertson 1943; Kent 1953; Renner 1975; Wilhelms et al. 1981). When the pipe downstream from the hydraulic jump is horizontal or is sloping upward, most of the air entrained by the jump is removed from the pipe (Falvey 1980). However, when the pipe slopes downward, the process of air transport downstream from the jump becomes important. This process is highly influenced by surface tension and viscosity. The entrained air bubbles will have approximately the same still water rise velocity in the model and prototype (Ervine and Elsawy 1975), giving a nonscaling of air transport. Several investigators have observed significant scale effects in the air transport in siphon models (Naylor 1935; CBIP 1956; Babb, Amorocho, and Dean 1967; Ervine and Elsawy 1975; Thatcher and Battson 1975; Copeland 1982).

13. Due to the scale effect in modeling air transport in siphons, priming times will be longer in the model and the ability to maintain

the priming seal at pump start-up may be overestimated. With respect to priming time, if adequate priming action exists in the model, then it is safe to conclude that the prototype priming action will be at least as good and probably better. With respect to maintaining the priming seal, the model scale effect will have an opposite impact. If more air is entrained in the prototype, then the weight of the water and air column, which holds the hydraulic jump in the siphon, will be reduced. If this weight is reduced significantly the priming seal will wash out of the siphon. Model scale effects related to washout are not as critical in this case as might be imagined because the pipe slopes upward in the saxophone outlet downstream from the hydraulic jump; and air entrainment is primarily a function of the Froude number of flow. It remains prudent to provide a safety factor in designing for washout when the design is based on model results. Scale effects associated with siphon modeling are reduced as the size of the model is increased. To date, research has not established an appropriate scale to adequately model siphon priming or washout, and model results must be interpreted with care.

14. The general relations expressed in terms of the model scale or length ratio are as follows:

Dimension	Ratio	Scale Relations
Length	$L_r = L$	1:4.36
Velocity	$V_r = L^{1/2}$	1:2.09
Time	$T_r = L^{1/2}$	1:2.09
Discharge	$Q_r = L^{5/2}$	1:39.8
Pressure	$P_r = L$	1:4.36
Frequency	$F_r = L^{-1/2}$	1:0.479

Values for water discharges, velocity, hydraulic grade line, and pressure fluctuation can be transferred quantitatively from model to prototype by means of the scale relations above; values for priming time and air discharge can only be transferred qualitatively. Unless otherwise noted, all results reported herein will be in prototype units.

PART III: TEST RESULTS

Method of Operation

15. Discharges simulated in the model ranged between 44 and 202 cfs; tailwaters ranged between el 419.0 and el 449.5. To study priming characteristics, the discharge was set with an air vent at the siphon crown opened. Priming was initiated by closing the air vent. The priming operation was timed with a stopwatch. The siphon was considered to be primed when all the air was removed from the downward sloping portion of the siphon. Discharge was checked at the end of each test; no significant changes were noted. Several priming operations were simulated where the discharge increased as the head decreased. Head-discharge relationships for these simulations were taken from the possible pump characteristic curve shown in Plate 2. For these simulations, discharge was increased by manually operating the regulating valve on the model so that the simulated discharge corresponded approximately to the head measured from the piezometer board and expected for the pump characteristic curve. These simulations were not intended to reproduce actual prototype priming times but were intended to develop a comparison between priming times with constant and varying discharges. To study the capability of the siphon to maintain a priming seal, the saxophone outlet and upstream pipe below the outlet elevation were filled with water by allowing a very small flow in the siphon. It is important that the outlet be filled with water before any significant flow comes through the siphon, because if the outlet is empty the supercritical flow coming down from the crown may have sufficient momentum to flow out of the saxophone outlet without forming a hydraulic jump and priming seal. Once the outlet was full of water, discharge could be increased to simulate possible prototype priming discharges. Washout tests were run with the air vent at the siphon crown opened. Discharge was increased in steps until the priming seal was washed out of the siphon.

Original Design Siphon

16. The original design siphon consisted of a 397-ft-long, 4-ft-diam pipe that extended from the pumping station, over and down the levee slope, to the outlet channel and the Illinois River. Three air vents were located at the siphon crown. At the outlet, the pipe turned upward at a 45-deg angle to form the saxophone outlet. The outlet was set at el 427.5 to limit the negative pressure in the siphon crown to 28 ft of water. Negative pressures in excess of 28 ft of water would probably cause cavitation. The type 1 (original) design siphon is shown in Figure 4.

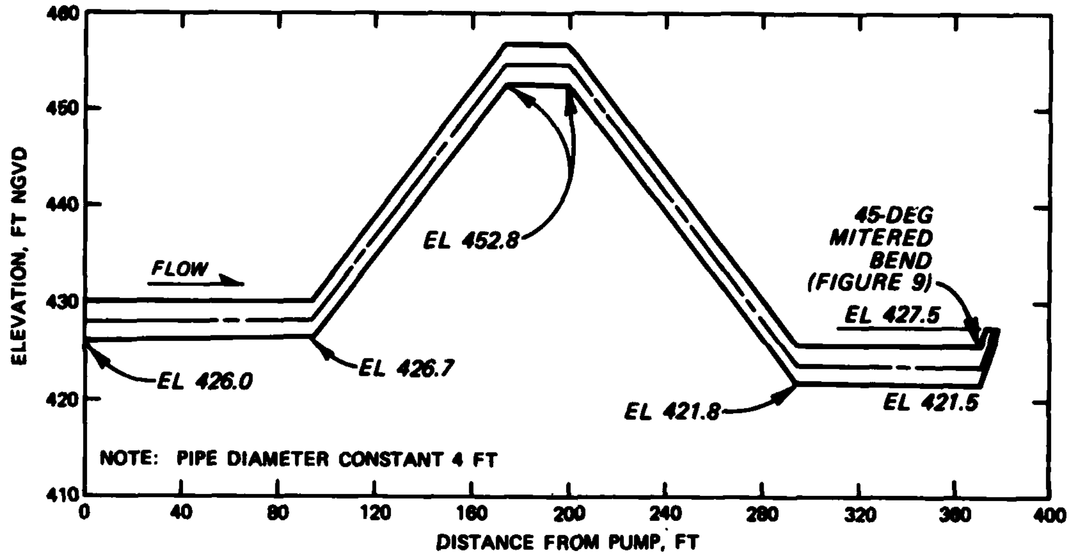

Figure 4. Type 1 (original) design siphon

17. It was determined in the model that the priming seal would wash out of the type 1 (original) design siphon at discharges greater than 102 cfs when the tailwater was below the outlet. Maximum discharges (pump capacity) expected before the start of priming ranged between 89 and 140 cfs depending on the sump water-surface elevation and the particular performance curve of the pumps finally acquired for the pumping station. In order to ensure maintenance of the priming seal for the maximum anticipated priming discharge, the hydrostatic head on the outlet was increased. This could have been accomplished by raising the outlet

elevation or by lowering the horizontal portion of the pipe upstream from the outlet. Raising the outlet elevation would decrease the amount of siphonic recovery that could be realized at low tailwaters for normal (primed) operations; therefore, lowering the horizontal portion of the outlet pipe was the preferred solution.

Experimental Outlet Designs

18. The effect of raising the elevation of the outlet on washout of the priming seal was determined in the model. Although this was not the preferred solution to the washout problem, model revisions were relatively simple and the results could be used to estimate how much the horizontal pipe should be lowered. The elevation of the type 1 design outlet was increased by 1, 2, and 4 ft in the model investigation. With the outlet raised 1 ft to el 428.5, washout occurred with discharges greater than 133 cfs. With the outlet at el 429.5 washout occurred at discharges greater than 155 cfs. When the outlet was raised 4 ft to el 431.5, washout did not occur with a discharge of 220 cfs, which is the maximum discharge that could be simulated in the model. The progression of the hydraulic jump toward washout with increasing discharge as determined in these tests is shown in Plate 3.

19. The effect of raising the outlet elevation a specific distance will not be the same as lowering the horizontal section of pipe upstream from the outlet the same distance. Lowering the pipe will increase the flow momentum upstream from the hydraulic jump so that a greater hydrostatic head will be required at the outlet to contain the same discharge. Results of the tests with increased outlet elevations, therefore, provided only a general idea of what to expect if the pipe was lowered.

20. The horizontal pipe upstream from the outlet was lowered 2 ft to el 419.5 in the type 2 design siphon (Figure 5). Center line of the outlet remained at the same station as in the type 1 design siphon so that the length of the horizontal pipe was shortened, but the total length of the siphon remained the same. The new elevation for the horizontal section of the pipe was based on the subject model tests with

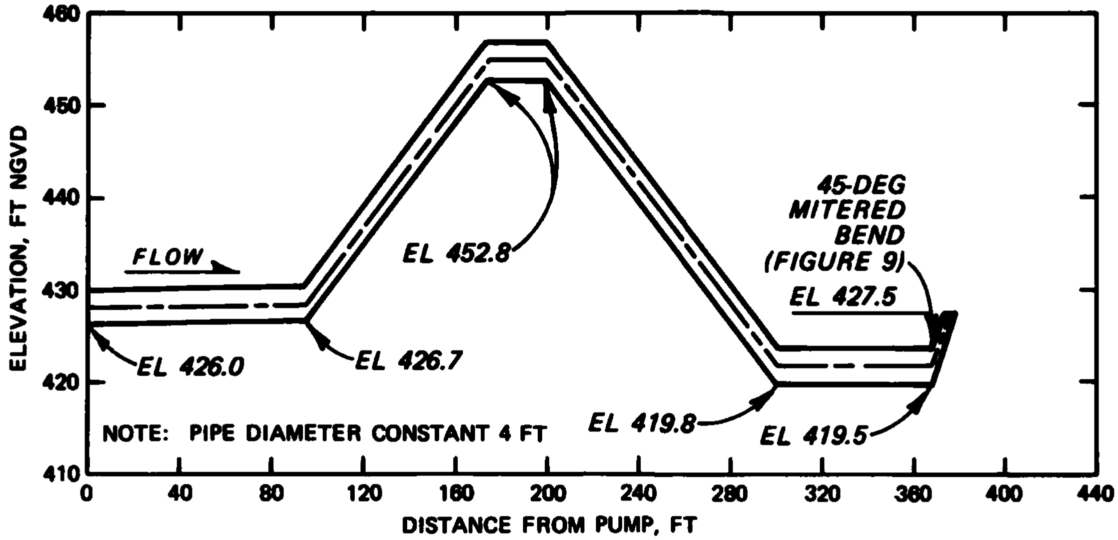

Figure 5. Type 2 design siphon

the raised outlet elevations and on determinations by engineers from the St. Louis District that soils and structural considerations limited lowering the pipe to el 419.5. It was determined by model testing that discharges greater than 133 cfs would wash out of the type 2 design siphon. This value is slightly less than the required design value of 140 cfs.

21. In order to increase the hydrostatic head provided by the outlet, a 90-deg saxophone outlet was used in the type 3 design siphon. With this modification, the center line of the outlet remained at the same station as in the type 2 design siphon, which resulted in a longer portion of horizontal pipe. In the model, the priming seal did not wash out of the type 3 design siphon at a discharge of 220 cfs (maximum that could be simulated in model). The type 3 design siphon eliminated the washout problem but resulted in increases in head losses. At the pump, heads with the type 3 design siphon were 0.6 ft greater with a discharge of 107 cfs and 1.3 ft greater with a discharge of 133 cfs than the heads measured with the type 1 design siphon.

22. Hydraulic conditions were more severe in the model tailbay with the 90-deg outlet than with the 45-deg outlet when the tailwater was below the outlet. The jet trajectory was considerably shorter with the 90-deg outlet and there was more turbulence and surface wave action. In addition, there is a greater thrust on the pipe with a 90-deg saxophone

outlet and flow from the outlet falls on the pipe and pipe supports upstream from the outlet. Engineers from the St. Louis District determined that these adverse conditions could be accounted for in the structural design.

23. In the type 4 design siphon, the 90-deg outlet elevation was lowered 1 ft to el 426.5. This modification would decrease the head at the pump for tailwaters below el 426.5 but would have no significant effect when the outlet was submerged. At low tailwaters, the head at the pump with the type 4 design siphon was 0.6 ft less than that observed with the type 3 design siphon with discharges of 107 and 133 cfs.

Recommended Outlet Design

24. A 60-deg saxophone outlet at el 427.5 was used in the type 5 design siphon. This design was capable of maintaining the priming seal and resulted in a smaller total head on the pump for the operating range of discharges than either the type 3 or 4 design siphons. The ability of the various designs tested to hold the hydraulic jump and maintain the priming seal is shown in Figure 6. Increasing the distance between the outlet elevation and the horizontal pipe provided a larger hydrostatic head which held the hydraulic jump at a greater distance from the outlet. This effect is demonstrated by comparing the type 1 and the type 2 design siphons which both had 45-deg outlets with the type 3 and the type 4 design siphons which both had 90-deg outlets. The distance between the outlet and the pipe was more important than the angle of the saxophone in determining the position of the hydraulic jump as can be seen by comparing the type 2, 3, and 5 design siphons. However, the angle of the saxophone appears to be the most significant factor in determining the ability to maintain the priming seal. The steeper outlets were aided by flow dropping back onto the outlet. This feature made it unnecessary to fill the saxophone outlet and upstream pipe below the outlet elevation because the backflow caused the priming seal to form even when the pipe was empty. The model facility did not have sufficient discharge capacity to determine actual washout discharges for the 60- and

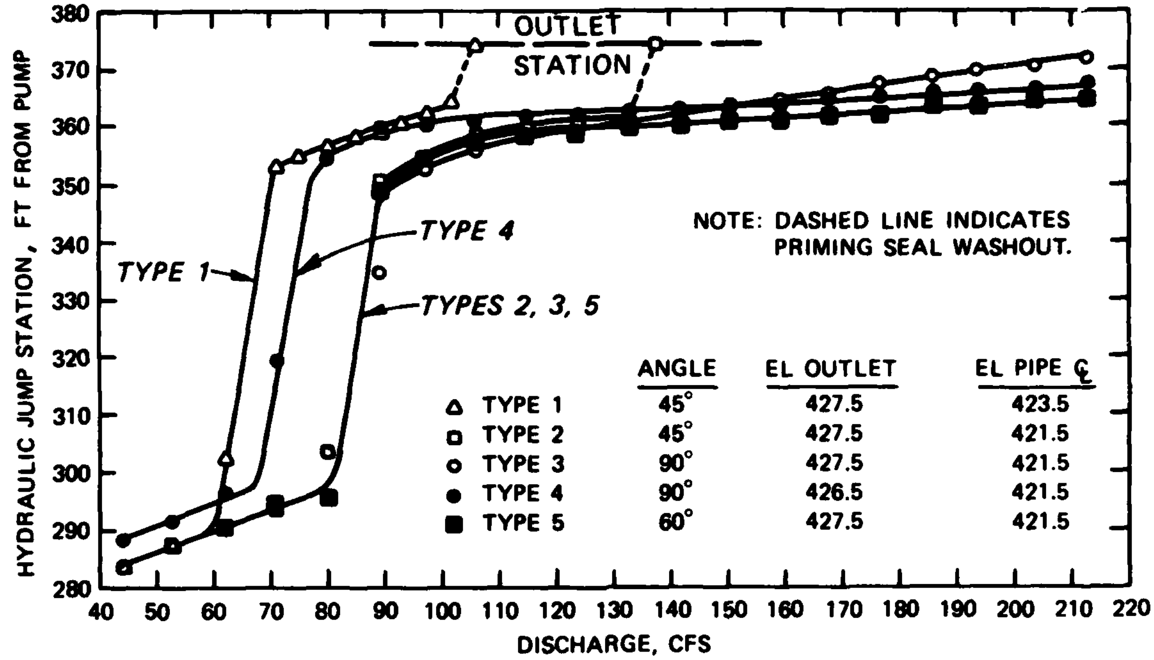

Figure 6. Progression of hydraulic jump toward outlet with increasing priming discharge

90-deg outlets. Total heads on the pump for the various designs with the tailwater below the outlet are compared in Figure 7. With the minimum operating discharge of 107 cfs, the type 5 design siphon provided about the same total head on the pump as the type 4 design siphon and about 0.6 ft less than the type 3 design siphon. With a normal low head operating discharge of 133 cfs, the type 5 design siphon provided about 0.6 ft less than the type 4 design siphon and about 1.2 ft less than the type 3 design siphon. The type 5 design siphon provided the best combination of low head losses and ability to maintain the priming seal of the designs tested in the model.

25. The amount of siphonic recovery (decrease in head elevation at the pump due to siphonic action) is limited to a maximum allowable negative pressure of 28 ft of water to prevent cavitation that could occur in the siphon when the pressure reaches the vapor pressure of water. The maximum negative pressure will occur at the point on the siphon with the highest elevation. The average maximum negative heads at the crown for the various siphon designs are compared in Figure 8. With

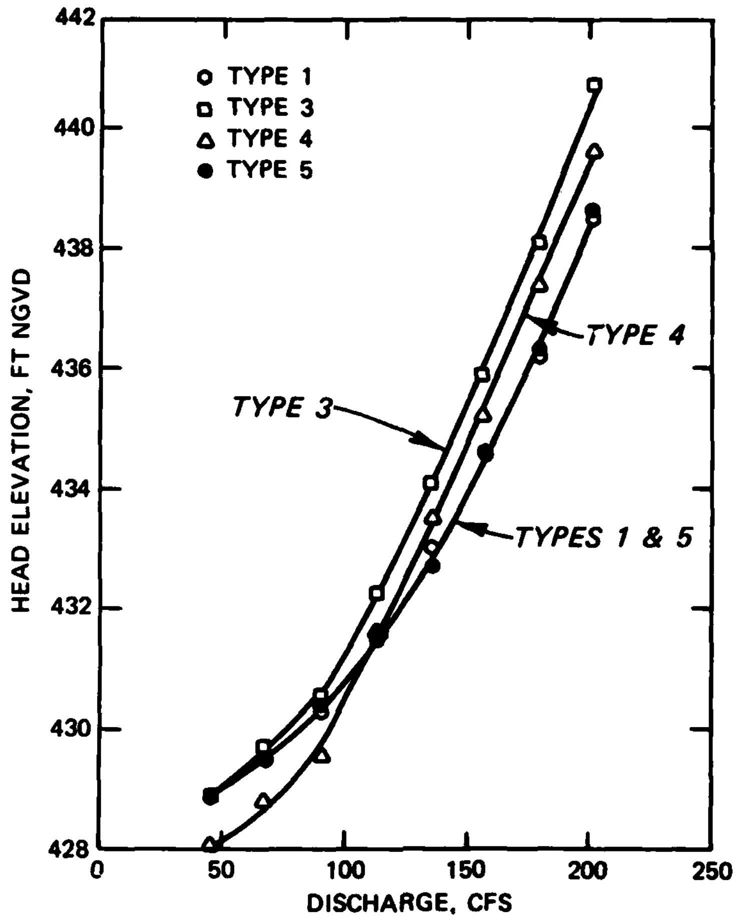

Figure 7. Total head elevation at pump with tailwater below outlet

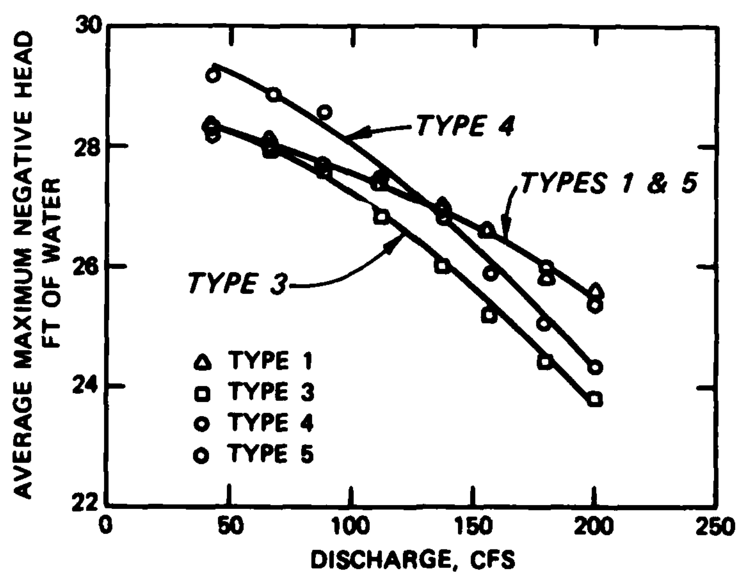

Figure 8. Average maximum negative head at siphon crown with tailwater below outlet and siphon primed

the type 5 design siphon and the minimum operating discharge of 107 cfs, the average maximum negative pressure was 27.4 ft of water. The actual maximum negative pressure will be somewhat lower than the average value due to the nonuniformity of the velocity and pressure distributions at the crown.*

Head on the Saxophone Outlet

26. The effective hydrostatic head at the saxophone outlet for normal (primed) operating conditions with free discharge was determined for the various outlet designs by extrapolating the pressure profile from upstream of the outlet (Plates 4-7). The effective head includes head losses due to the double mitered bend in the saxophone outlet. This procedure was used because the velocity and pressure distributions are distorted in the saxophone outlet, and the effective hydrostatic head on the system cannot be readily determined by the piezometers. The effective head on the 90-deg outlets was higher because of higher bend losses and because the effective tailwater created by the direction of the jet trajectory was greater. The effective heads on the 60- and 45-deg outlets were similar. The additional bend loss that would normally be expected with a greater flow angle change was apparently offset by the longer interior mitered section used in the 60-deg outlet. The saxophone outlet designs tested are shown in Figure 9 and the effective hydrostatic heads are shown in Figure 10.

Operating Head Losses

27. The model was used to estimate the total head that the pump would be operating against at the beginning of priming, at tailwaters below the outlet elevation of 427.5, and at tailwater elevations of 435.0, 442.0, and 449.5. The hydrostatic head and pressure fluctuation at various locations along the siphon were measured using piezometers. These data were plotted and the profile extrapolated to sta 0+00, which is the location of the prototype pump (Plates 8-12). The head determined in the model was reduced to account for frictional differences in the model

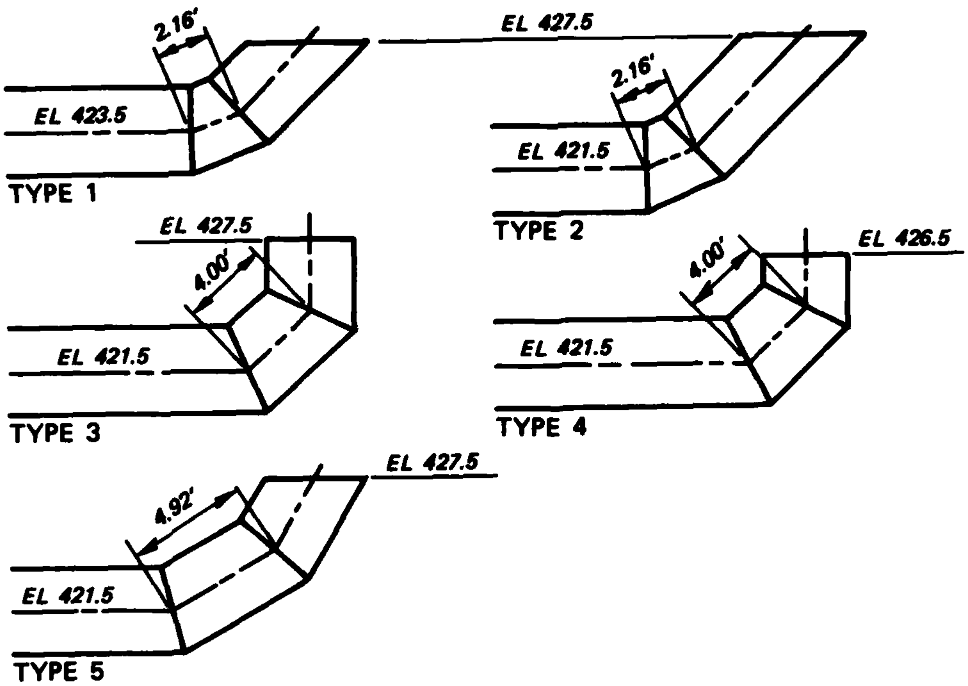

Figure 9. Saxophone outlets tested in model study

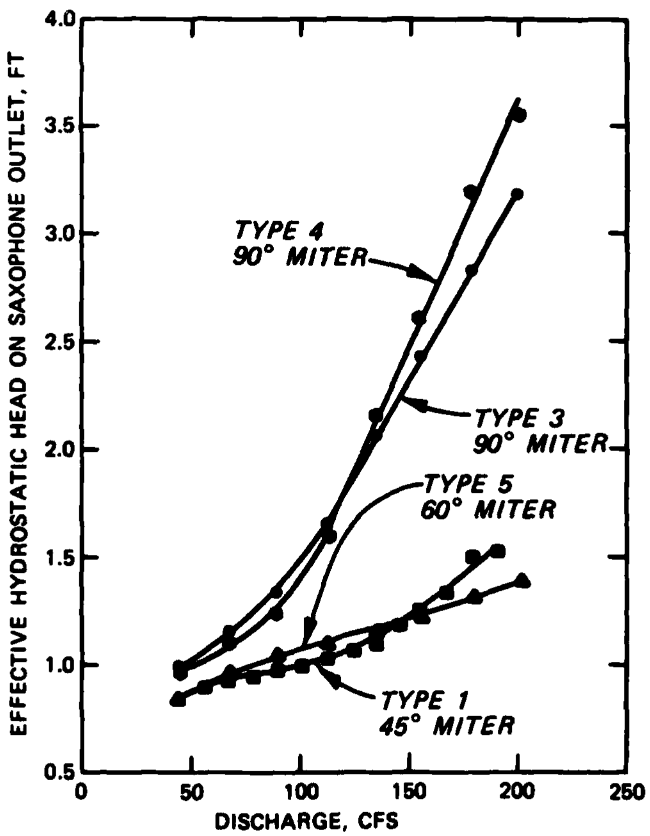

Figure 10. Effective hydrostatic head on saxophone outlets

and prototype. The model was assumed to be a smooth pipe with Darcy-Weisbach friction factors between 0.016 and 0.012. The prototype friction factors ranged between 0.012 and 0.013 and were determined for a k_s value of 0.0003 ft as recommended in HDC Sheet 224-1/1 (USA, CE 1968) for steel pipes with tar coating. Results of the procedure used to adjust for frictional differences are shown in Table 1. Calculations for the adjusted heads and hydraulic grade line elevations at the pump for various discharges are shown in Tables 2-6; results are plotted in Plates 13-17.

28. The primary function of this model investigation was to study the siphon's priming characteristics and washout potential, a phenomenon governed primarily by gravity forces. When the siphon is primed, viscous forces become more important. In order to use the model to estimate head losses in the siphon, it was necessary to make adjustments to the data to account for incorrectly scaled roughness elements. The assumptions required to make the necessary adjustments render the results only as reliable as normal hydraulic calculations used to determine head losses in a closed conduit.

Priming Characteristics

29. Hydraulic characteristics in the siphon during priming are shown in a series of photographs (Photos 1-6) for a constant discharge of 120 cfs. In Photo 1 the air vent at the siphon crown is open and the hydraulic jump (not visible due to outlet flume) is stationary just upstream from the outlet. Initially, the air vent is opened in order to relieve the positive pressure that accompanies pump start-up. When the air vent is closed, the priming process begins. The hydraulic jump entrains air that must be transported down the pipe by the flow. Initially, air removal is rapid and the hydraulic jump moves quickly up the siphon (Photos 2 and 3). As the distance required for air transport increases, the air removal rate decreases. Large air pockets form downstream from the jump (Photo 4) and move upstream, eventually blowing through the hydraulic jump. When this happens, the hydraulic jump moves

slightly downstream so that the general upward progress of the jump is characterized by pulsations. As the hydraulic jump nears the siphon crown, only a small percentage of the air entrained by the jump is actually transported out of the siphon (Photo 5). Air bubbles entrained by the hydraulic jump eventually rise to the top of the siphon and form small air pockets. These air pockets will continue to move downstream as long as the drag forces provided by the flow are large enough to overcome their buoyant forces. The final stages of priming are characterized by a steady train of small air pockets moving upstream and air bubbles being gradually transported downstream out of the siphon. The primed siphon is shown in Photo 6. Due to the hydraulic characteristics of the priming process, the siphonic recovery is rapid during initial phases of priming and much slower during the final stages of priming.

30. Priming times were measured in the type 5 design siphon with constant discharges and a range of tailwaters. Results of these tests indicated that tailwater had an insignificant effect on priming time when the discharge was constant. It was also apparent that when the discharge was less than about 110 cfs, priming times increased significantly with small decreases in discharge. Priming times determined in these tests are shown in Figure 11 and are presented in prototype units; however, duration of the priming phase determined by model tests is greater than would be expected in the prototype. The prototype siphon will prime faster because, during priming, the discharge will be increasing as the head on the pump decreases; whereas in the model tests, the discharge was held constant. This effect will be significant at low tailwaters but much less significant at high tailwaters where the air removal and siphonic recovery rates are slower. In addition, the priming times determined in the model study may be greater than in the prototype because the air entraining and air transport capabilities of the model may be somewhat less than the prototype due to scale effects. Thus, the model test results cannot be transferred quantitatively to the prototype and must be interpreted with care.

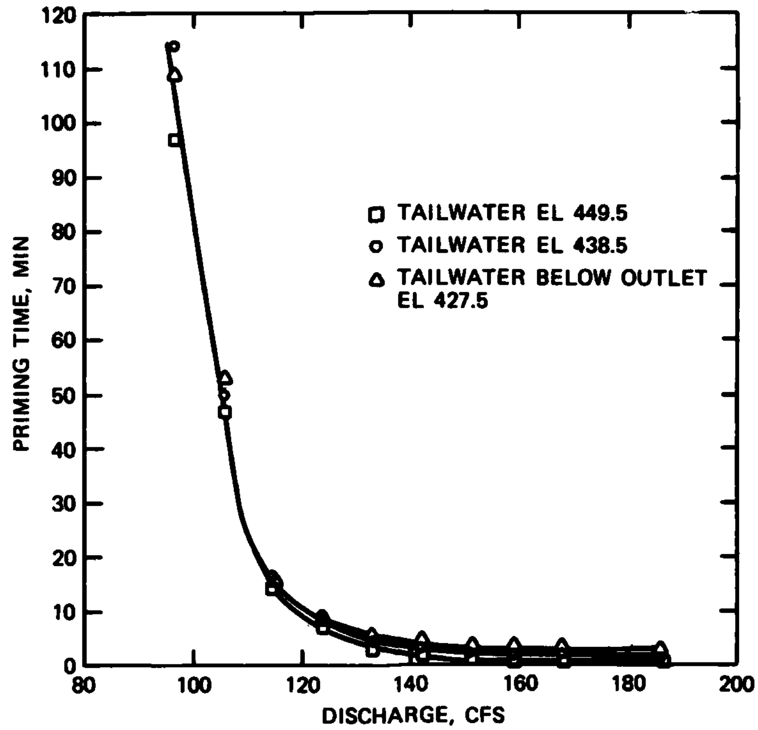

Figure 11. Priming times for constant discharges, variable tailwaters, type 5 design siphon

Air Escape Vents

31. The effect of an air escape vent on priming characteristics was determined in the model. An air escape vent could be located on the downstream (riverward) leg of the siphon to assist priming with high tailwaters. Its purpose is to shorten the distance required for transport of entrained air and to reduce the upstream movement of air pockets that have buoyant forces greater than the drag forces provided by the flow. Elevation of the air escape vent must be below the hydraulic grade line in the siphon conduit or it will act as a siphon breaker. In addition, if the hydraulic jump is located below the vent station at the start of priming, the vent must be closed until the hydraulic jump has moved upstream past the vent station. Operation of the air escape vent which is operated during priming is illustrated in Figure 12. Effectiveness of the air escape vent is a function of its location on the

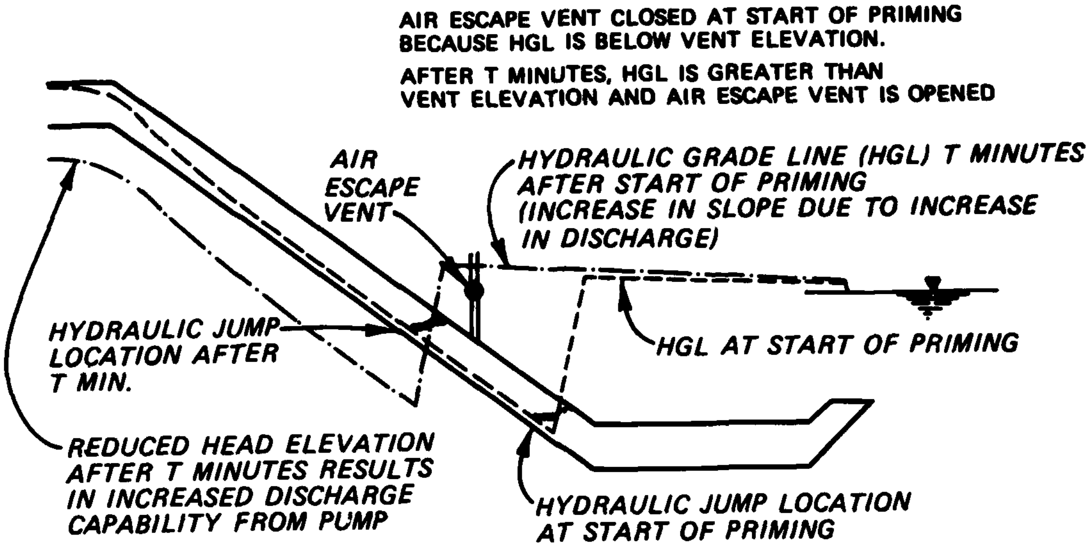

Figure 12. Operation of air escape vent

siphon. If the vent is at a higher location on the siphon, air will be removed faster and priming times will be reduced; however, the tailwater must be higher for the vent to function. The frequency of high tailwater is an important consideration in deciding whether an air escape vent should be provided or not. Air escape vents at representative elevations of 435.0 and 442.0 were tested in the model with a range of tailwaters.

32. Effects of the air escape vents on priming times for constant discharges were compared in the model with a tailwater elevation of 445.0. The vents significantly reduced priming times at the lower discharges which are representative of expected priming discharges (Figure 13). The vent at el 442.0 was more effective than the vent at el 435.0; operating both vents did not result in a significant improvement in priming conditions. In these tests, priming was considered complete when all the air was removed from the siphon.

33. The amount of time required for complete priming at low discharges may be excessive; but under certain conditions, significant partial priming or siphonic recovery may occur rapidly. The model was used to determine siphonic recovery at various times after the start of priming for a constant discharge of 89 cfs. This discharge is the minimum priming discharge acceptable in the pumping station's design

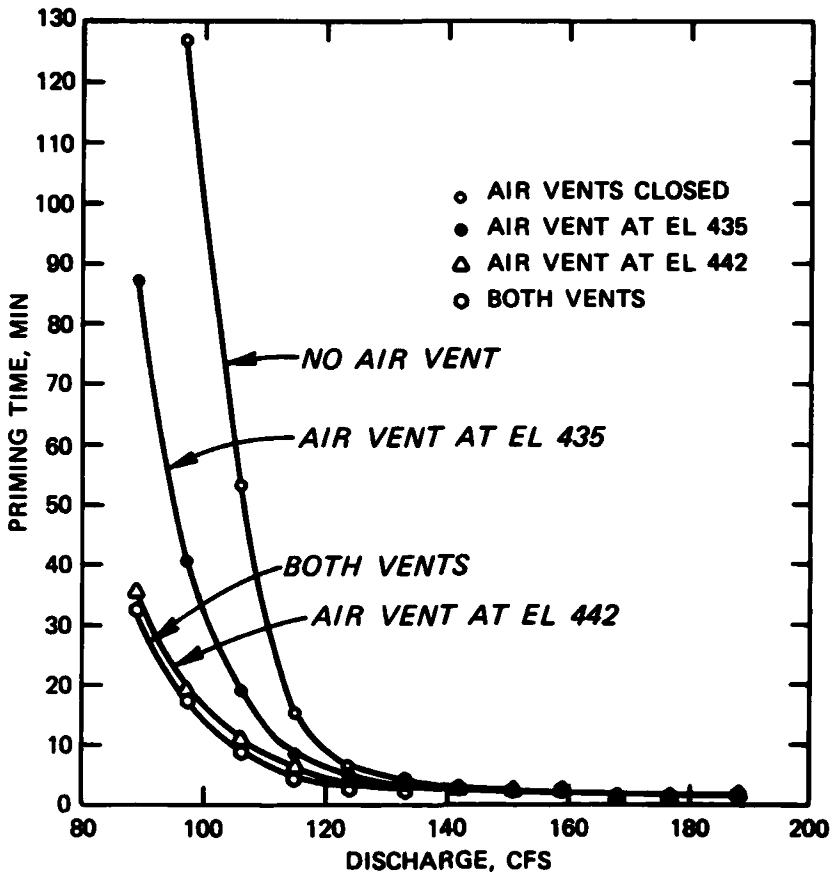

Figure 13. Priming times for constant discharges with air escape vents at tailwater el 445.0

specifications. When the tailwater was below the outlet (el 427.5), significant partial recovery occurred rapidly; but full recovery could not be achieved in the model (Plate 18). At a tailwater elevation of 438.5, siphonic recovery was determined with and without an air escape vent at el 435.0 (Plate 19). Without the vent, recovery was rapid at first but slowed down considerably after a head recovery of about 9 ft. With the air vent, about 15 ft of head was recovered before the recovery rate slowed down. The air vent at el 442.0 could not function at this tailwater elevation. At tailwater elevations of 445.0 and 449.5, siphonic recovery was determined without an air escape vent and with vents at el 435.0 and 442.0 (Plate 20). At these higher tailwaters the rate of siphonic recovery is slow without the air vents and considerably faster with the vents. Complete siphonic recovery was achieved faster

with the vent at el 442.0 than at el 435.0. Model results suggest that significant partial siphonic recovery may be achieved in a relatively short time without the use of air escape vents at low tailwaters; but at higher tailwaters, air escape vents are required if rapid recovery is desired.

34. Actual priming operations with varying discharge were simulated in the model with a high and a low tailwater. As the siphon primes, the head on the pump is reduced and the discharge increases. Variation of discharge with head is dependent on the particular performance curve of a specific pump. Since this curve will remain unknown until the contract is awarded, a pump performance curve was estimated (Plate 2) and used to demonstrate the effect of increasing discharge on priming time. Results are shown in Figure 14. With a low tailwater, discharge increases rapidly from 98 to 158 cfs and priming is accomplished in about 7 min. With the high tailwater, discharge increases from 98 to 110 cfs at a slower rate, and about 50 min is required for priming. With an air escape vent at el 435.0, priming time was reduced to about 19 min. With the vent at el 442.0, about 9 min was required for priming. Air escape vents provided significant improvement in priming times with high tailwaters and varying discharges.

35. Surging of flow occurred in the vents during the early stages of priming and adequate measures should be taken to prevent saturation and scour of the embankment by flows that spill out of the vent. This could be accomplished by providing protection and drainage around the vent opening.

Effect of Reducing Cross-Sectional Area at Siphon Crown

36. The last part of the siphon to flow full during priming is at the crown and immediately downstream. The air removal rate is much slower in the last stage of siphon priming because entrained air bubbles must travel farther to escape. It was postulated that if the cross-sectional area of the crown was reduced so that the pipe would flow full, priming times would be reduced.

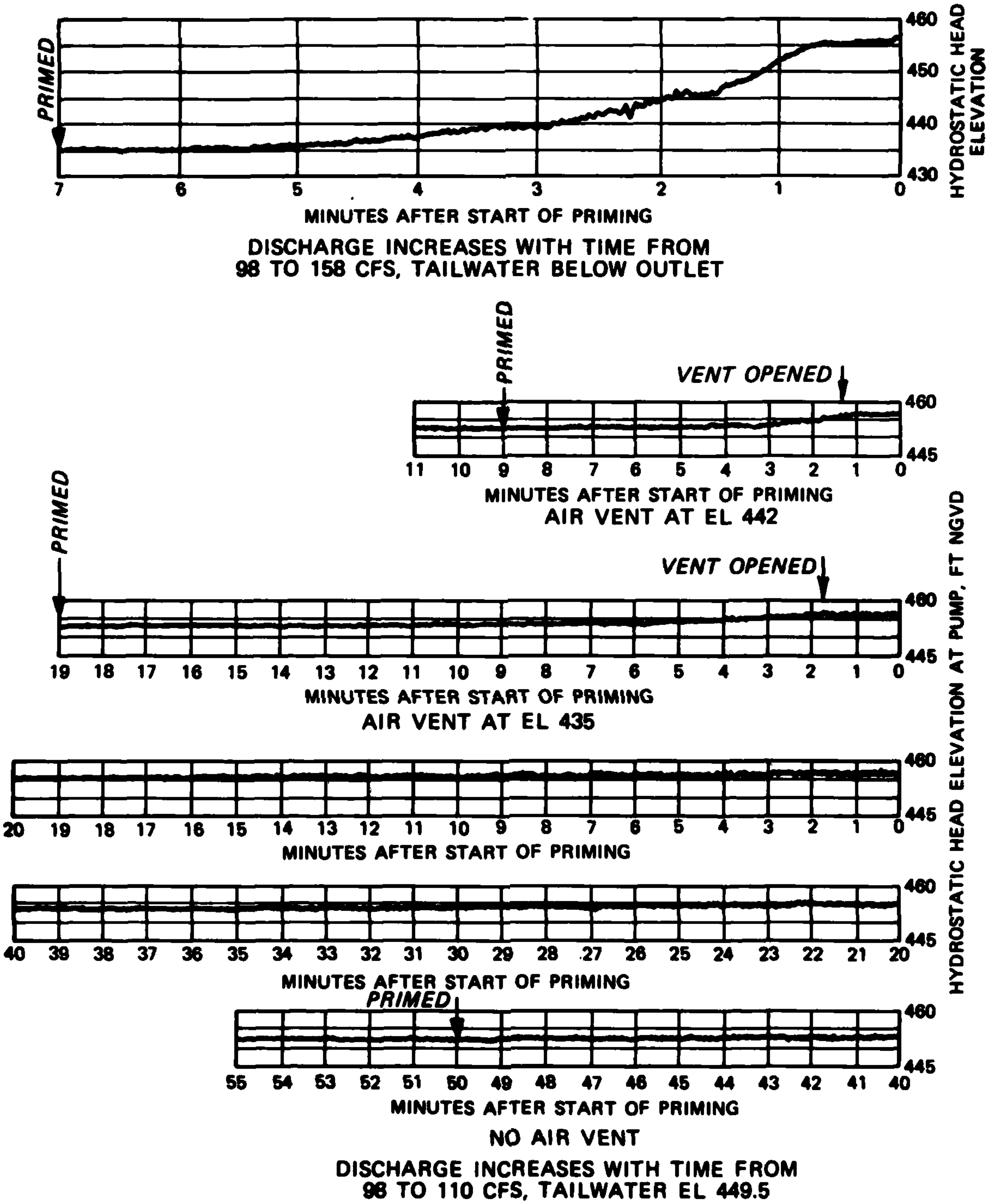

Figure 14. Hydrostatic head elevations during priming at high and low tailwaters

37. Two designs were tested in the model (Figure 15) with the type 5 design outlet and compared with the type 1 (original) design crown. The type 2 design crown consisted of plugging the top 1 ft of the 4-ft-diam pipe along the horizontal crown section and providing a transition downstream. The type 3 design crown extended the reduced cross-sectional area an additional 16 ft downstream. Priming times for a range of constant discharges were determined for each crown design with the tailwater below the outlet. Results are compared in Figure 16. The crown modifications provided for a decrease in priming times at the lower discharges. The type 2 design crown was successful in forcing the horizontal portion of the siphon crown to flow full during initial stages of priming. The type 3 design crown was successful in causing the reduced section to flow full at an earlier phase of priming so that the last portion of the siphon to flow full was the transition reach. Thus, the modifications were successful in forcing the siphon to flow full at the

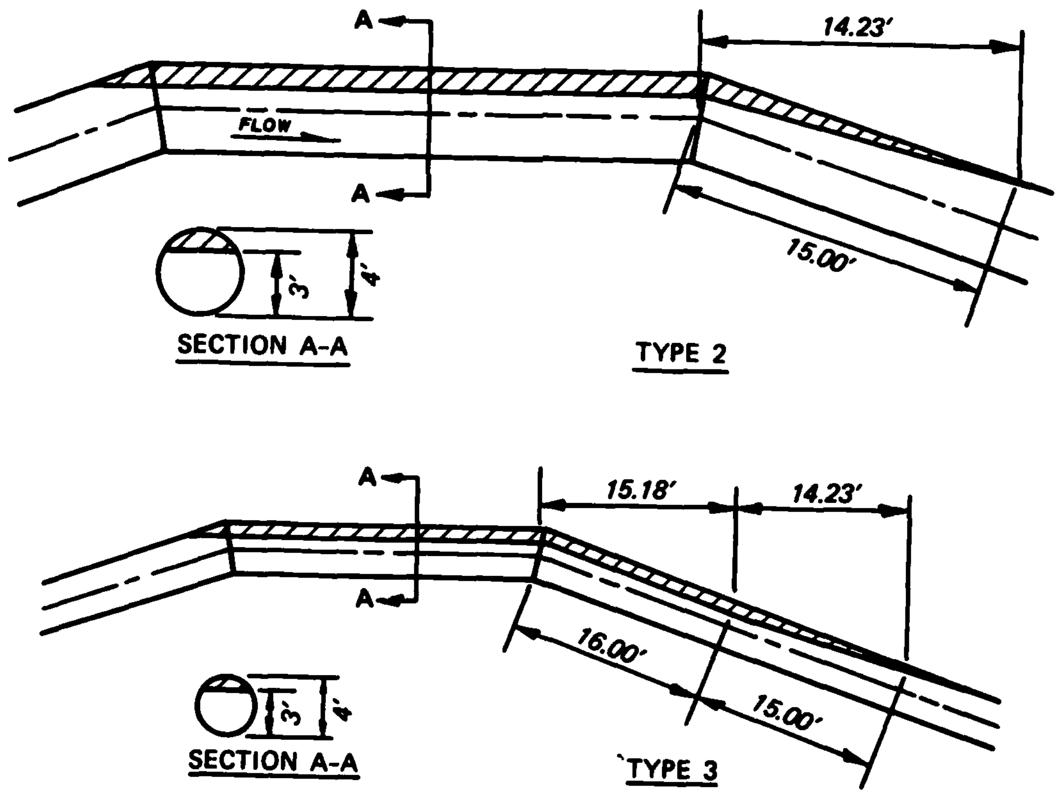

Figure 15. Siphon crown modifications

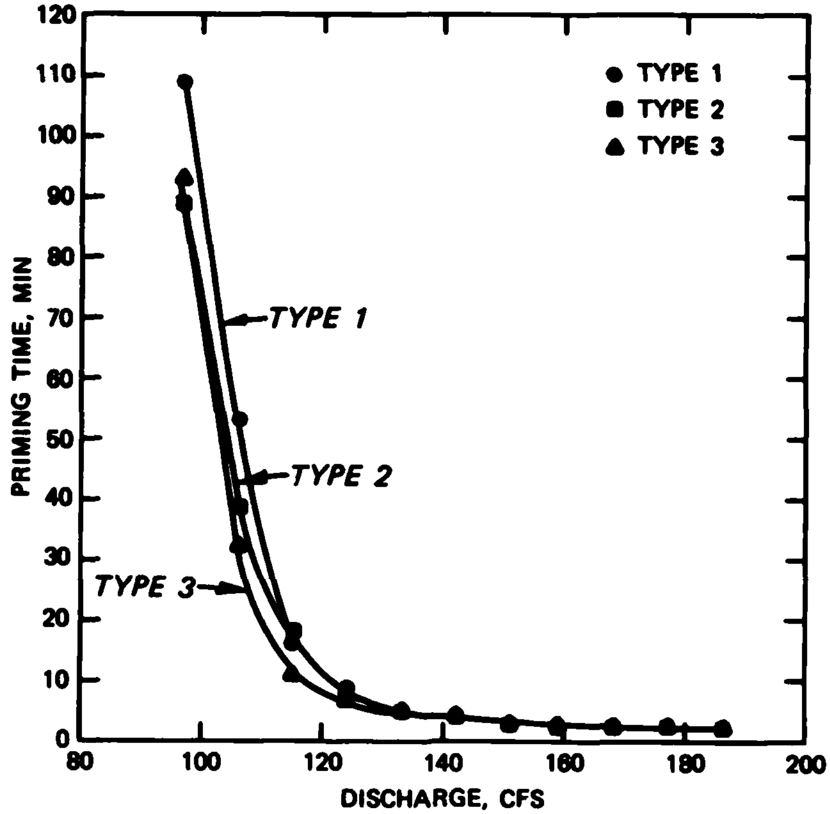

Figure 16. Effect of crown modifications on priming times

crown early in the priming phase but unsuccessful in reducing priming times sufficiently to justify incorporation into the final design. Extending the modified section farther downstream or replacing the 4-ft-diam pipe with a smaller diameter pipe could effectively reduce priming times, primarily by increasing velocities and thus increasing air removal rates.

38. Velocities through the modified portions of the siphon were increased due to the area reduction. This resulted in an increase in total head losses at the pump for the normal (primed) operating conditions. At the design discharge of 133 cfs, the increase in head loss was found to be 0.35 ft with the type 2 design crown and 0.50 ft with the type 3 design crown. Increases in head losses for other discharges are shown in Figure 17. Additional cross-sectional area reductions would result in even greater head losses, which were considered to be unsatisfactory by the sponsors.

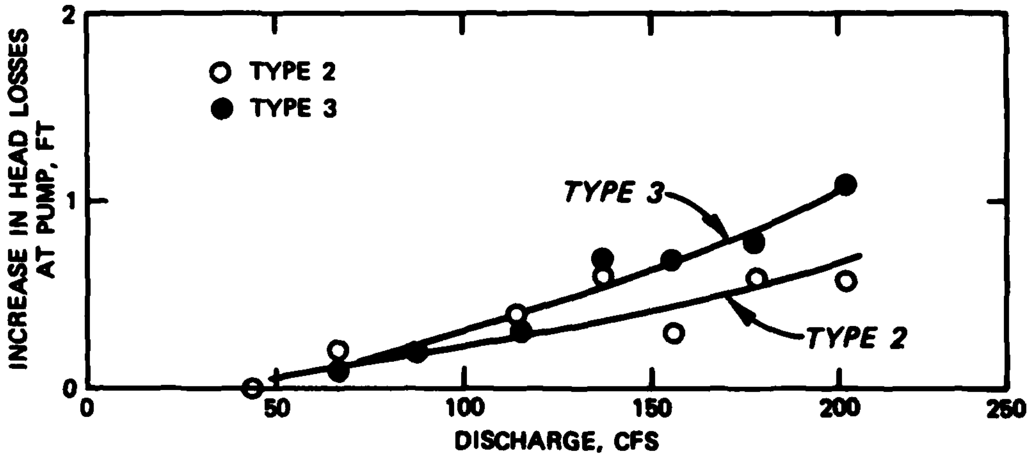

Figure 17. Effect of crown modifications on head losses

Pressure Regulation with Air Vent

39. Siphonic head recovery can be limited by allowing small amounts of atmospheric air to enter through the vents at the top of the siphon conduit. Consideration has been given to this type of operation in the conversion of existing pumping station discharge pipes to siphons where the elevation between the crown and outlet permits recoveries in excess of 28 ft. This type of operation could also be used to increase the head on the pump for operations where the static head on the pump is reduced below the design limit. This method of operation was demonstrated in the model with the type 4 design outlet. The model was allowed to operate for 2 hr (prototype time) and no change in the average head was observed. Pressure fluctuations increased significantly due to the unsteady flow conditions created by the air entrainment and removal process. Maximum and minimum pressures along the length of the siphon for a water discharge of 168 cfs and representative air discharges of 7 and 4 cfs are shown in Plates 21 and 22, respectively. Pressure fluctuations at the pump are shown in Plate 23. Severity of pressure fluctuations varies with water and air discharges.

Velocity Distributions Upstream from Outlet

40. Velocity distributions were measured just upstream from the type 4 design outlet with both the siphon primed and with the air vent open. Velocities were measured along the vertical axis of the discharge pipe with a pitot tube located 4 ft upstream from the center of the outlet (Plate 24). Two measurements were made with the siphon primed and the tailwater below the outlet. Velocities measured for discharges of 107 cfs and 186 cfs (which represent the possible minimum and maximum operating discharges, respectively, to be expected with the pump characteristic curves supplied by the St. Louis District) are plotted in Plate 24. These measurements show that flow tends to concentrate at the top of the pipe when the siphon is primed, indicating a backwater effect. Velocity measurements with the air vent open and the tailwater below the outlet were made for discharges of 140 cfs and 89 cfs (the expected maximum and minimum priming discharges, respectively, Plate 25). Under these conditions, flow was characterized by irregular velocity fluctuation and considerable air entrainment. Flow concentrated near the bottom of the pipe when the air vent was open and a hydraulic jump occurred just upstream of the position where the velocities were measured. These measurements were made in the type 4 design outlet to provide information relative to structural design of the outlet, and would not be expected to be significantly different in the recommended type 5 design outlet.

PART IV: CONCLUSIONS

41. Pumping station siphons must be designed so that velocities are sufficient to remove air at the priming discharge and a priming seal will remain in place upstream from any open air vents or an unsubmerged outlet. A priming seal can be maintained with a properly designed saxophone outlet. Water flows down the riverward leg of the siphon until it reaches the adverse slope of the outlet. The saxophone outlet must have a sufficient adverse slope and horizontal distance to force a hydraulic jump in the siphon. The hydraulic jump entrains air which must be carried out of the siphon by the flow so that the siphon will prime. This model investigation determined that a 60-deg adverse slope and a horizontal distance of 6 ft from the end of the horizontal section of the siphon conduit center line to the outlet center line was sufficient to maintain the priming seal for the McGee Creek pumping station siphon.

42. Priming characteristics may be studied qualitatively using physical hydraulic models, realizing that there is a definite scale effect in modeling a water and air mixture. Priming times in prototypes will be less than those obtained in models. This provides for a built-in safety factor, because if the model primes it is safe to predict that the prototype will prime. Conversely, the discharge that will wash out the priming seal may be underestimated by a model. It is therefore prudent to provide a safety factor in the design of saxophone outlets. Siphon models should be constructed to scales sufficiently large to minimize scale effects. The state of the art does not yet allow determination of exact model-to-prototype scale effects. Prototype tests of this structure will be invaluable in this regard.

43. Priming times can be significantly reduced with an air escape vent when the tailwater is high. Elevation of the air escape vent must be below the hydraulic grade line in the siphon conduit or it will act as a siphon breaker. Usefulness of the vent is a function of its location on the siphon conduits. If the vent is at a higher location on the conduit, air will be removed faster and priming times will be reduced; however, the tailwater must be higher than the vent for the vent to

function. The optimum vent location, therefore, depends on the frequency of high tailwaters.

44. Reducing the cross-sectional area at the crown of the siphon did not reduce priming times sufficiently to justify incorporation into the final design. Additional head losses occurred with the reduced cross sections after the siphon was primed.

45. The amount of siphonic head recovery for any given tailwater can be reduced by allowing small amounts of atmospheric air to enter through the vents at the top of the siphon conduit. Pressure fluctuations and head losses in the siphon are much greater with an air pocket and hydraulic jump in the siphon than with the siphon fully primed.

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Table 1

Adjustment for Head Losses due to Model and Prototype Friction Differences

Discharge Prototype cfs	Velocity Model fps	Reynolds Number Model* $\times 10^5$	Darcy-Weisbach Friction Factor** Model	Darcy-Weisbach Friction Factor† Prototype	Velocity Head Prototype	Friction Head Adjustment Prototype Feet††	
Q_p	V_m	R_m	f_m	f_p	$V_p^2/2g$	L = 397 ft	L = 200 ft
44	1.69	1.76	0.0160	0.0129	0.19	0.1	0.0
66	2.53	2.64	0.0149	0.0125	0.44	0.1	0.1
89	3.37	3.52	0.0140	0.0122	0.77	0.1	0.1
112	4.28	4.46	0.0135	0.0120	1.25	0.2	0.1
136	5.16	5.38	0.0130	0.0119	1.81	0.2	0.1
156	5.94	6.19	0.0127	0.0118	2.39	0.2	0.1
179	6.83	7.12	0.0124	0.0118	3.17	0.2	0.1
202	7.62	7.94	0.0120	0.0118	3.94	0.1	0.0

* Temperature = 85°F.

** Model assumed to be smooth pipe.

† f_p calculated with $k_s = 0.0003$ (tar-coated steel pipe).

†† Head adjustment $= (f_m - f_p)\,\frac{L}{D}\,\frac{(V_p)^2}{2g}$; L = length of pipe flowing full.

Table 2

<u>Head Elevations* at Pump at Start of Priming</u>

<u>Type 1 Design</u>

Discharge cfs	Hydraulic Grade Line at Pump El**	Head Adjustment for Friction† ft	Adjusted Hydraulic Grade Line at Pump El	Velocity Head $V^2/2g$ ft	Adjusted Total Head at Pump El	Pressure Fluctuation at Pump El
44	455.8	0.0	455.8	0.2	456.0	0.0
66	456.4	0.1	456.3	0.4	456.7	0.1
89	456.9	0.1	456.8	0.8	457.6	0.1
112	457.5	0.1	457.4	1.2	458.6	0.2
136	458.0	0.1	457.9	1.8	459.7	0.2
156	458.6	0.1	458.5	2.4	460.9	0.2
179	459.0	0.1	458.9	3.2	462.1	0.3
202	459.4	0.0	459.4	3.9	463.3	0.4

* All elevations are in feet referred to NGVD.
** Extrapolated from model data in Plate 8.
† Table 1.

Table 3

Head Elevations* at Pump, Tailwater Below Outlet, Siphon Primed

Type 5 Design

Discharge cfs	Hydraulic Grade Line at Pump El**	Head Adjustment for Friction† ft	Adjusted Hydraulic Grade Line at Pump El	Velocity Head $V^2/2g$ ft	Adjusted Total Head at Pump El	Pressure Fluctuation at Pump El
44	428.8	0 1	428.7	0.2	428.9	0.0
66	429.2	0.1	429.1	0.4	429.5	0.1
89	429.8	0.1	429.7	0.8	430.5	0.1
112	430.4	0.2	430.2	1.2	431.4	0.2
136	431.1	0.2	430.9	1.8	432.7	0.2
156	432.4	0.2	432.2	2.4	434.6	0.2
179	433.3	0.2	433.1	3.2	436.3	0.3
202	434.7	0.1	434.6	3.9	438.5	0.3

* All elevations are in feet referred to NGVD.
** Extrapolated from model data in Plate 9.
† Table 1.

Table 4

Head Elevations* at Pump, Tailwater El 435.0, Siphon Primed

Type 5 Design

Discharge cfs	Hydraulic Grade Line at Pump El**	Head Adjustment for Friction† ft	Adjusted Hydraulic Grade Line at Pump El	Velocity Head $V^2/2g$ ft	Adjusted Total Head at Pump El	Pressure Fluctuation at Pump El
44	435.5	0.1	435.4	0.2	435.6	0.0
66	436.0	0.1	435.9	0.4	436.3	0.1
89	436.4	0.1	436.3	0.8	437.1	0.2
112	437.0	0.2	436.8	1.2	438.0	0.2
136	438.0	0.2	437.8	1.8	439.6	0.2
156	439.0	0.2	438.8	2.4	441.2	0.5
179	440.1	0.2	439.9	3.2	443.1	0.3
202	441.3	0.1	441.2	3.9	445.1	0.6

* All elevations are in feet referred to NGVD.
** Extrapolated from model data in Plate 10.
† Table 1.

Table 5

Head Elevations* at Pump, Tailwater El 442.0, Siphon Primed

Type 5 Design

Discharge cfs	Hydraulic Grade Line at Pump El**	Head Adjustment for Friction† ft	Adjusted Hydraulic Grade Line at Pump El	Velocity Head $V^2/2g$ ft	Adjusted Total Head at Pump El	Pressure Fluctuation at Pump El
44	442.4	0.1	442.3	0.2	442.5	0.0
66	442.8	0.1	442.7	0.4	443.1	0.1
89	443.4	0.1	443.3	0.8	444.1	0.1
112	444.1	0.2	443.9	1.2	445.1	0.1
136	445.0	0.2	444.8	1.8	446.6	0.2
156	445.8	0.2	445.6	2.4	448.0	0.2
179	447.1	0.2	446.9	3.2	450.1	0.1
202	448.4	0.1	448.3	3.9	452.2	0.3

* All elevations are in feet referred to NGVD.
** Extrapolated from model data in Plate 11.
† Table 1.

Table 6

Head Elevations* at Pump, Tailwater El 449.5, Siphon Primed

Type 5 Design

Discharge cfs	Hydraulic Grade Line at Pump El**	Head Adjustment for Friction† ft	Adjusted Hydraulic Grade Line at Pump El	Velocity Head $V^2/2g$ ft	Adjusted Total Head at Pump El	Pressure Fluctuation at Pump El
66	450.4	0.1	450.3	0.4	450.7	0.1
89	450.9	0.1	450.8	0.8	451.6	0.2
112	451.7	0.2	451.5	1.2	452.7	0.1
136	452.6	0.2	452.4	1.8	454.2	0.2
156	453.4	0.2	453.2	2.4	455.6	0.3
179	454.6	0.2	454.4	3.2	457.6	0.3
202	455.8	0.1	455.7	3.9	459.6	0.4

* All elevations are in feet referred to NGVD.
** Extrapolated from model data in Plate 12.
† Table 1.

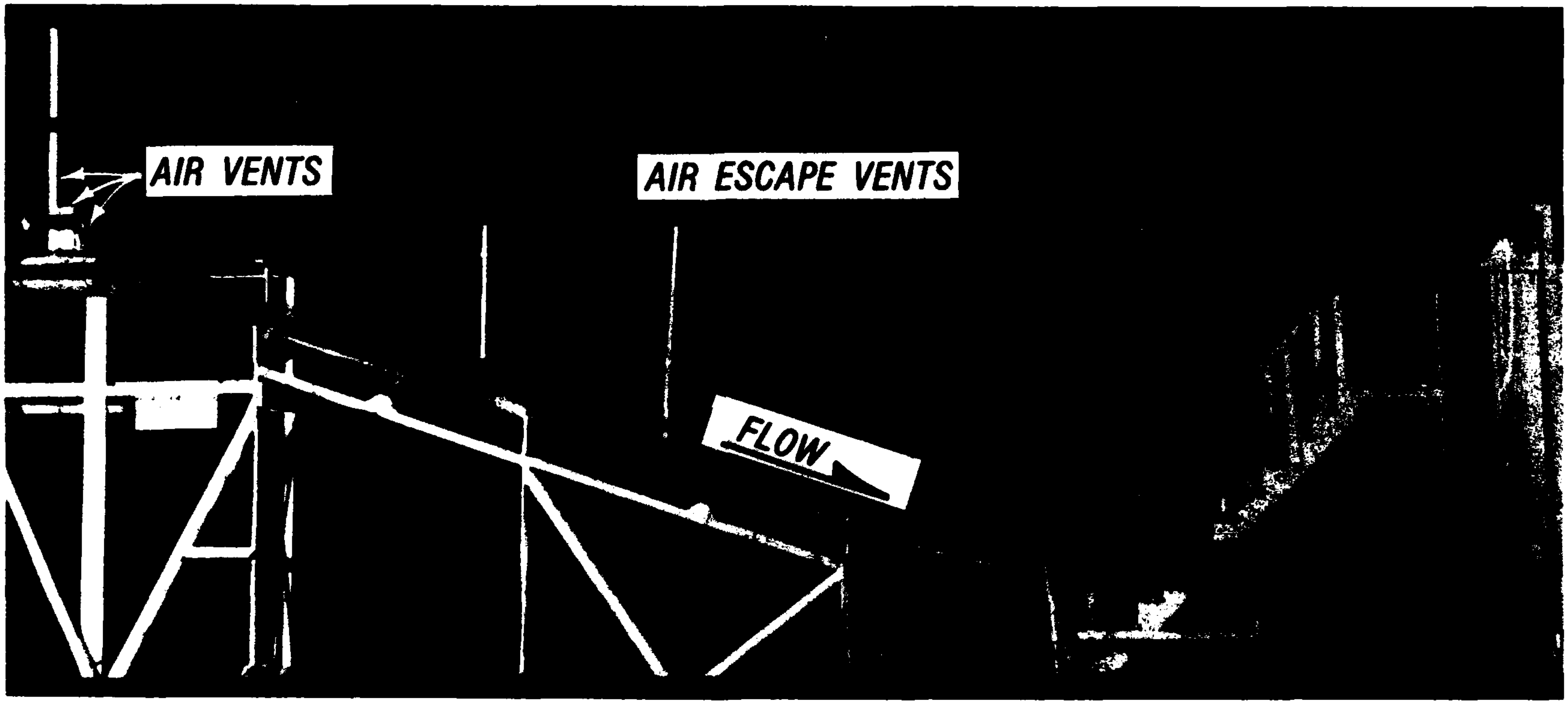


Photo 1. Priming characteristics, air vent open; discharge 120 cfs, time 0 sec

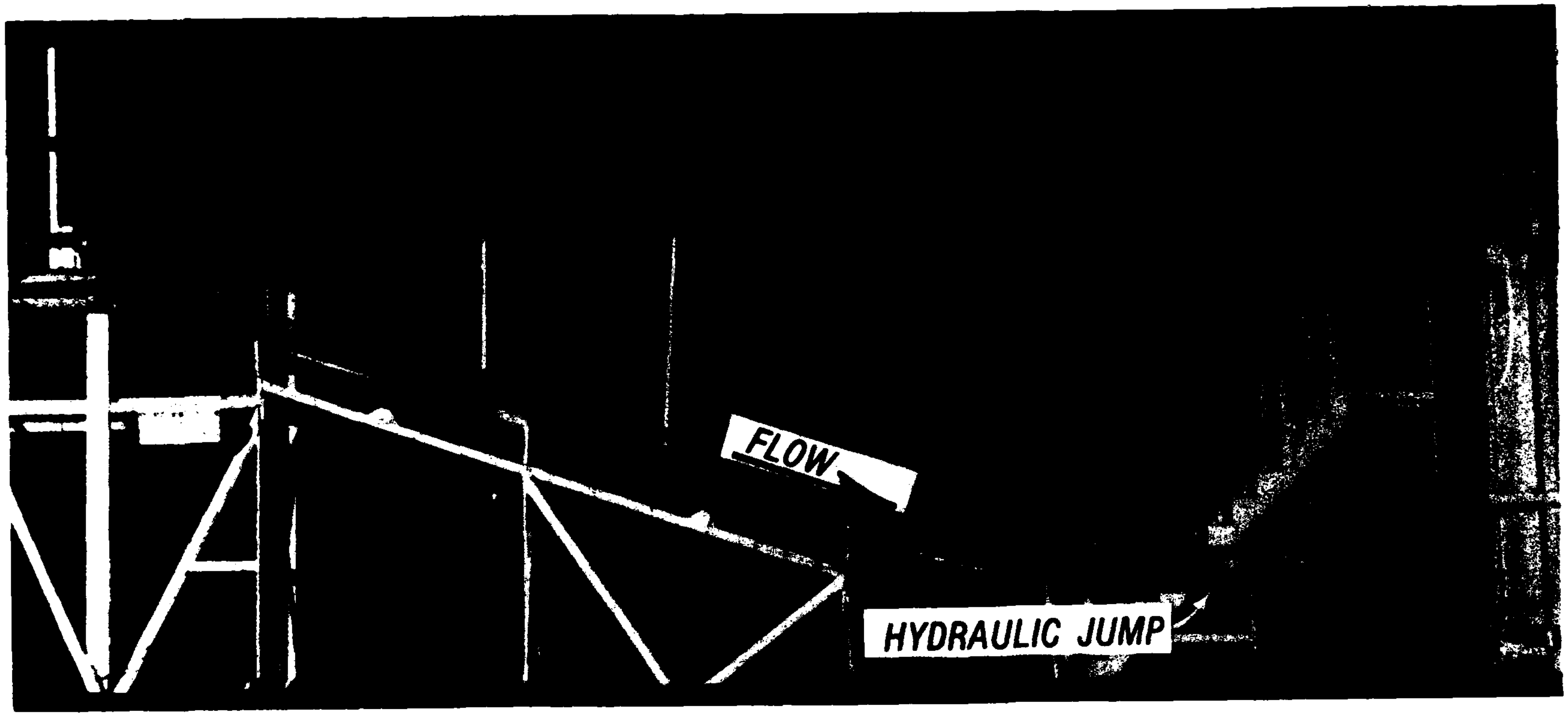


Photo 2. Priming characteristics; discharge 120 cfs, time 20 sec

Photo 3. Priming characteristics; discharge 120 cfs, time 1 min

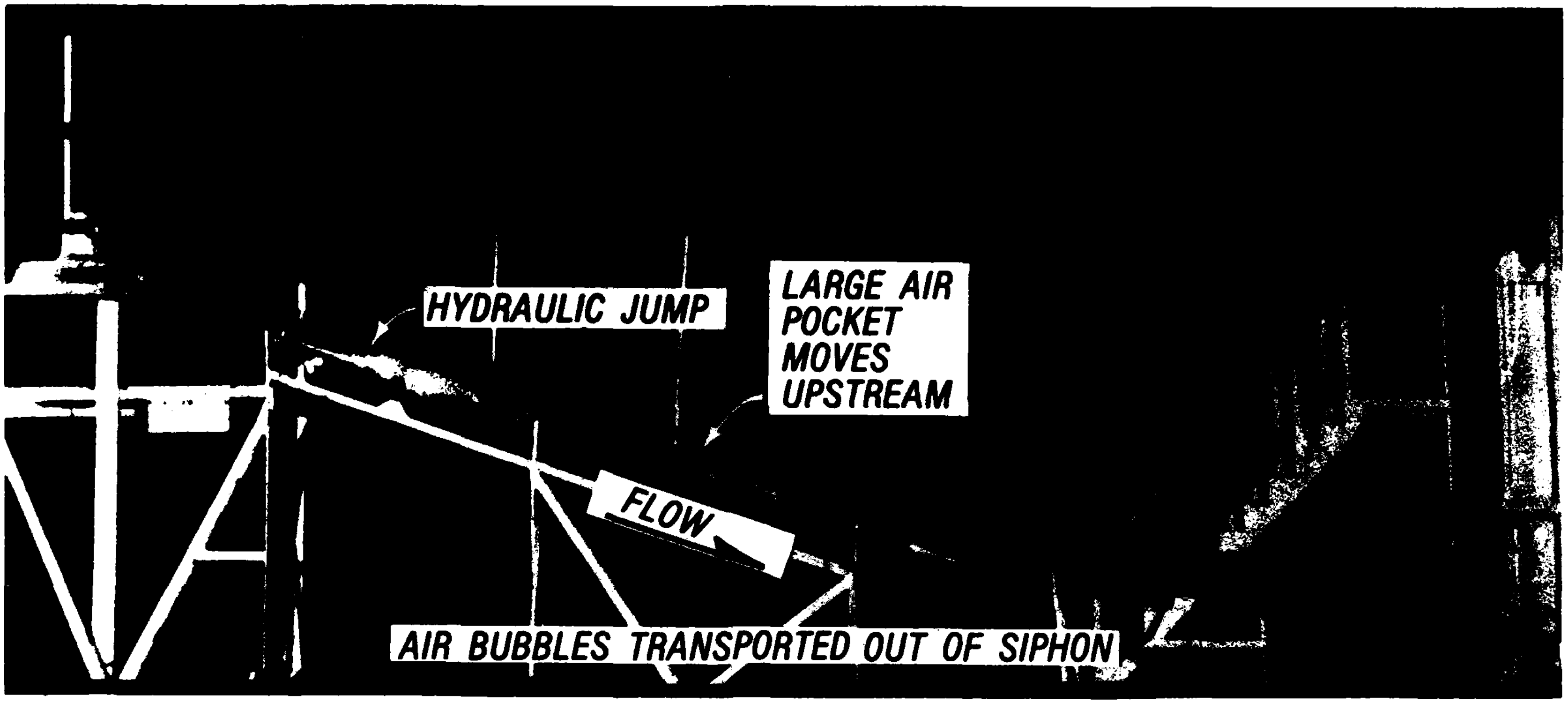


Photo 4. Priming characteristics; discharge 120 cfs, time 2 min

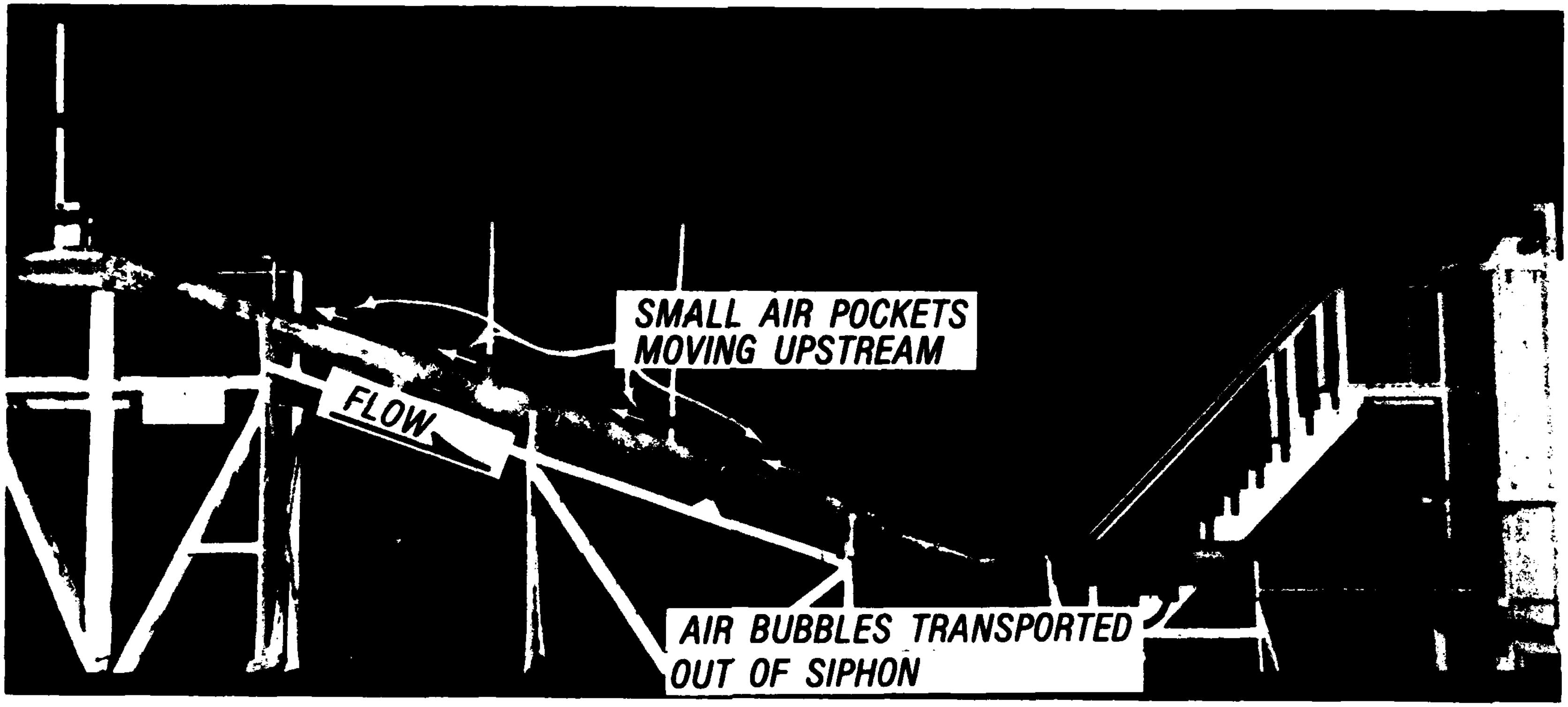


Photo 5. Priming characteristics; discharge 120 cfs, time 4 min

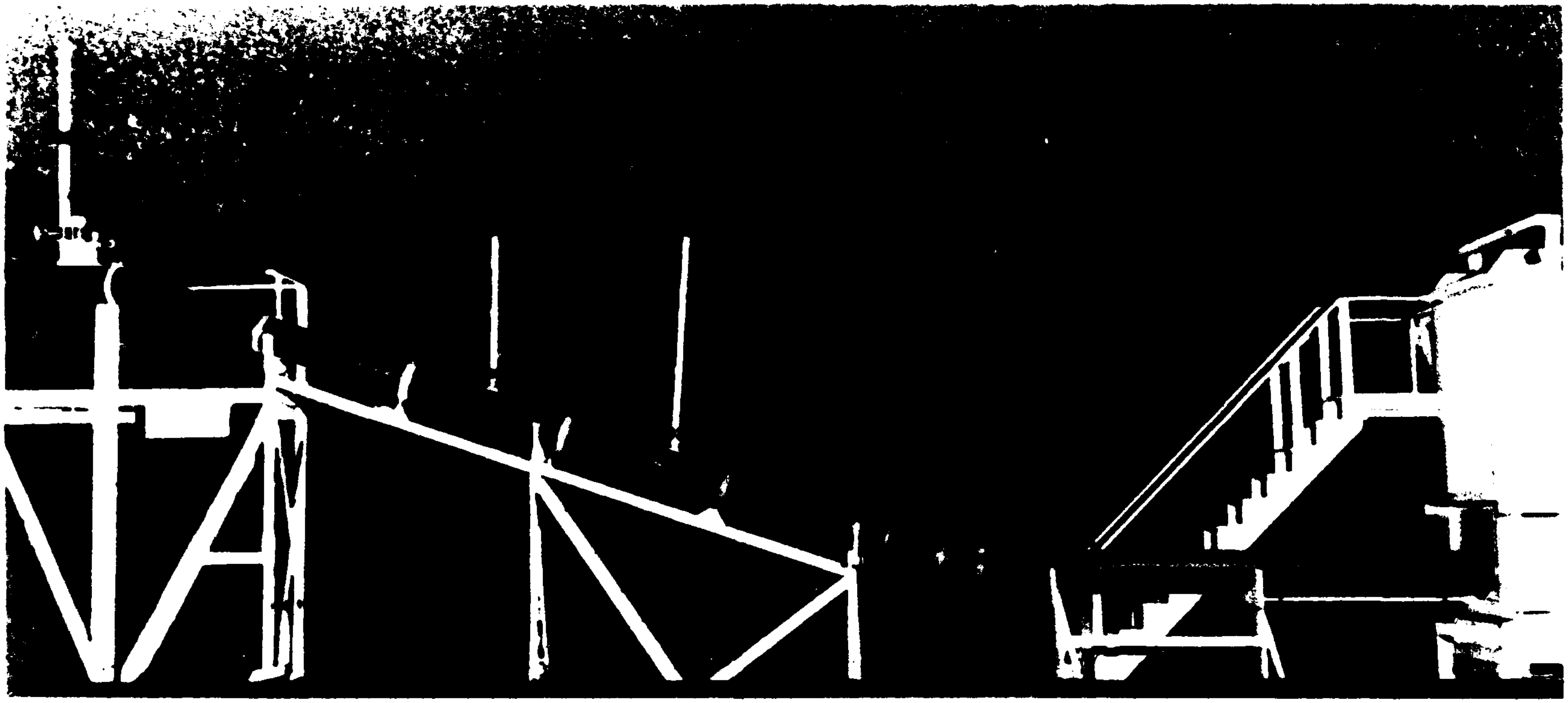
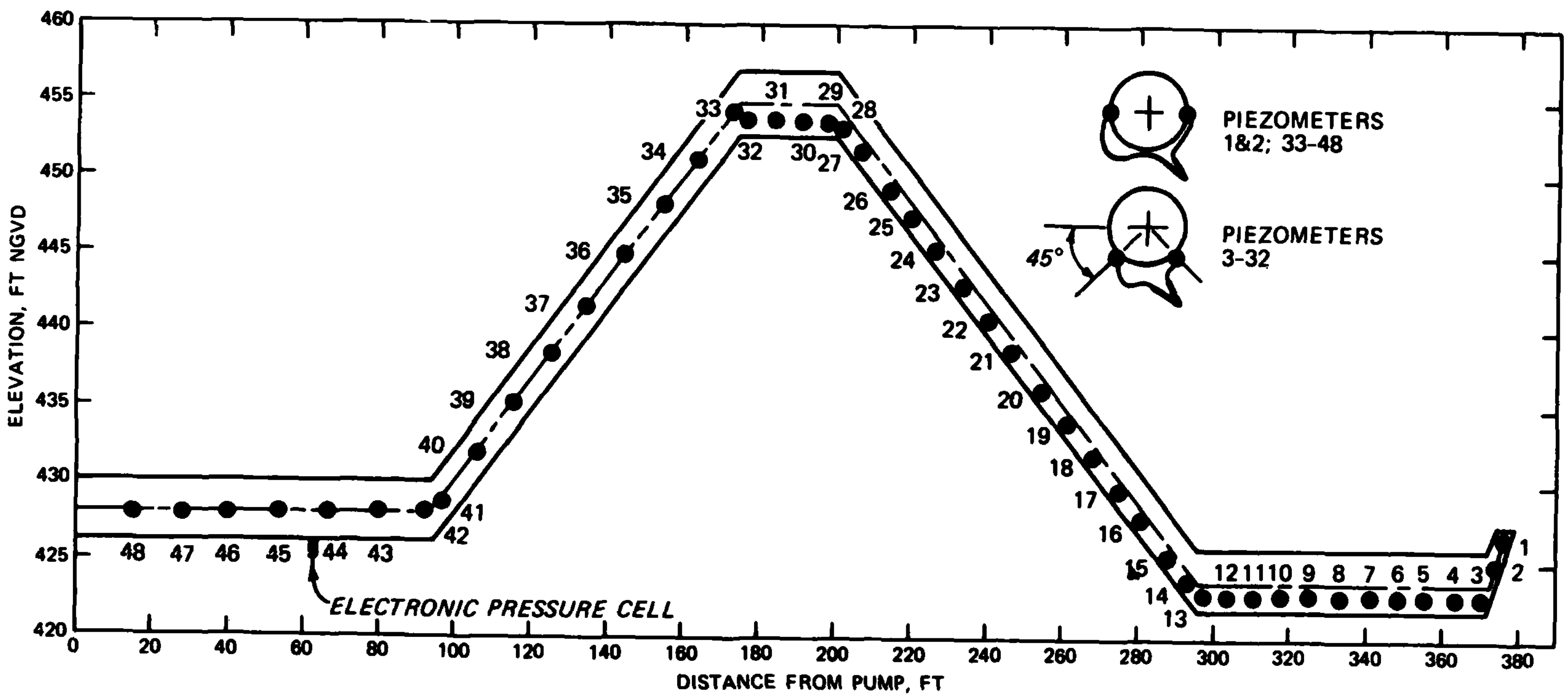
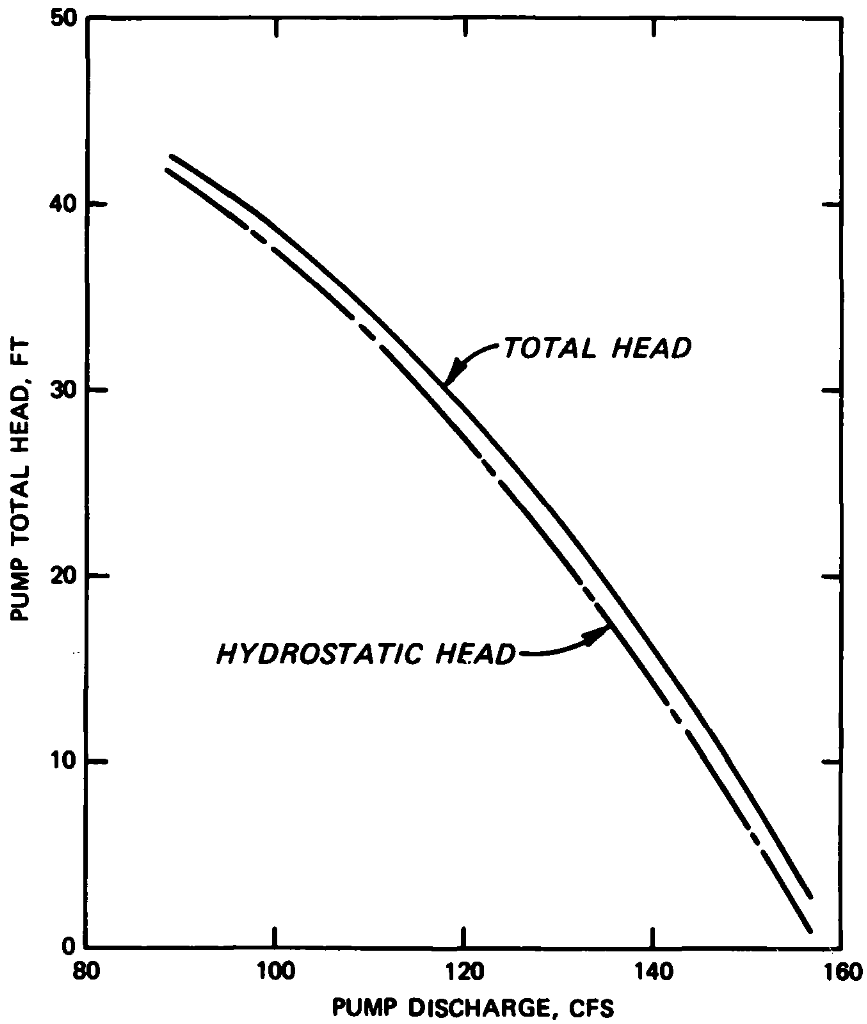


Photo 6. Priming characteristics, primed; discharge 120 cfs; time 10 min



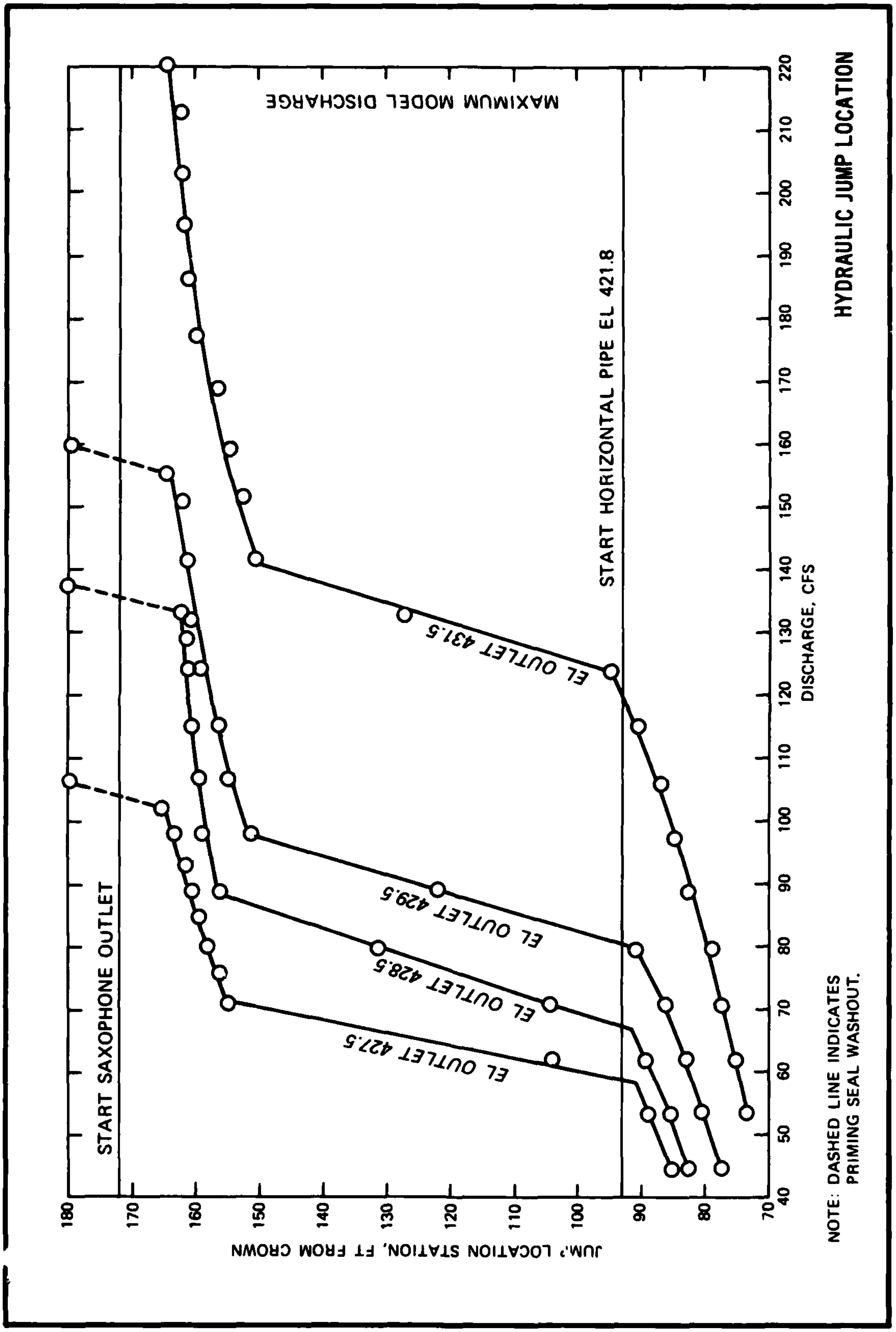
PIEZOMETER LOCATIONS

PLATE 1



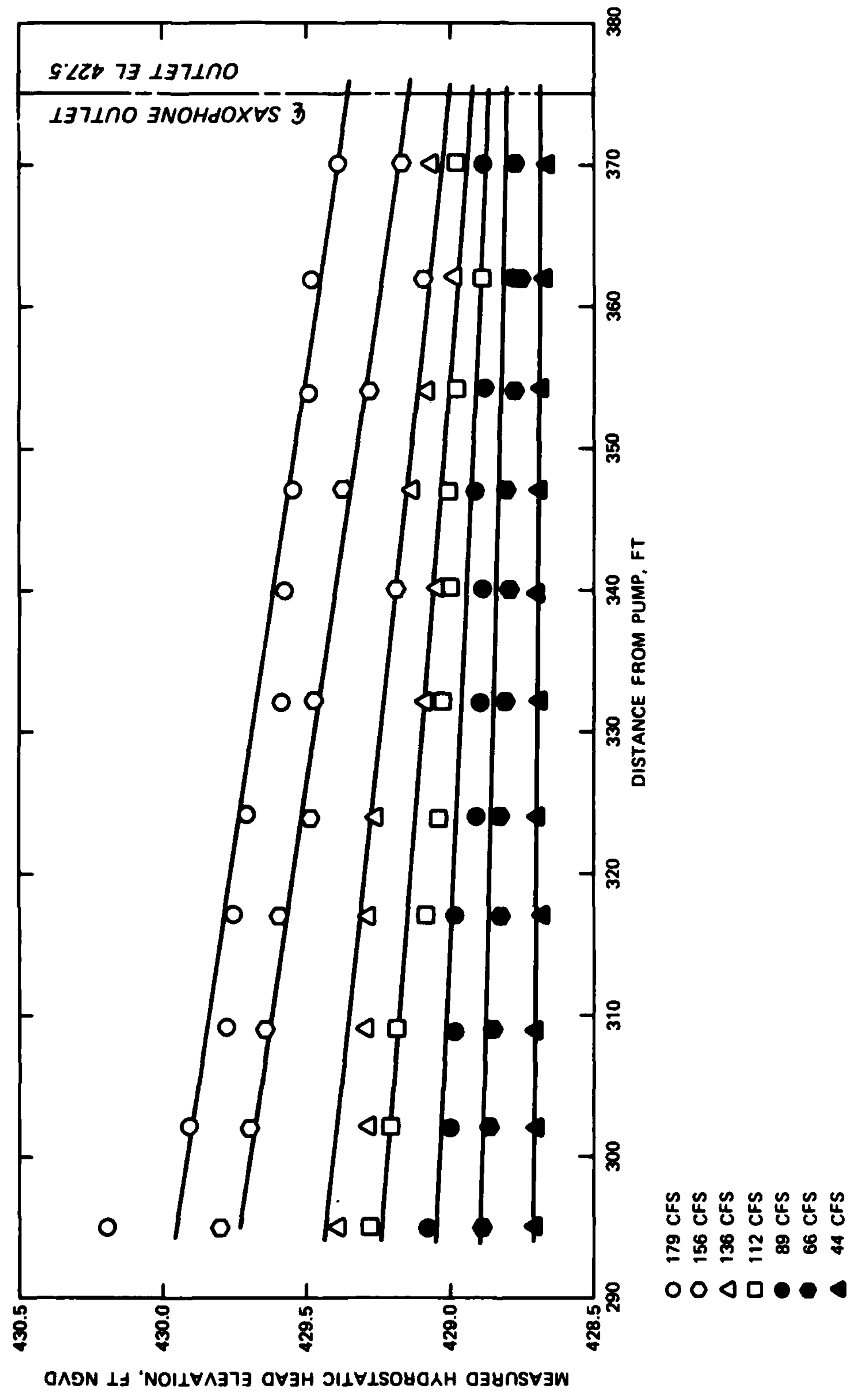
POSSIBLE
PUMP CHARACTERISTIC
CURVE

PLATE 2



NOTE: DASHED LINE INDICATES PRIMING SEAL WASHOUT.

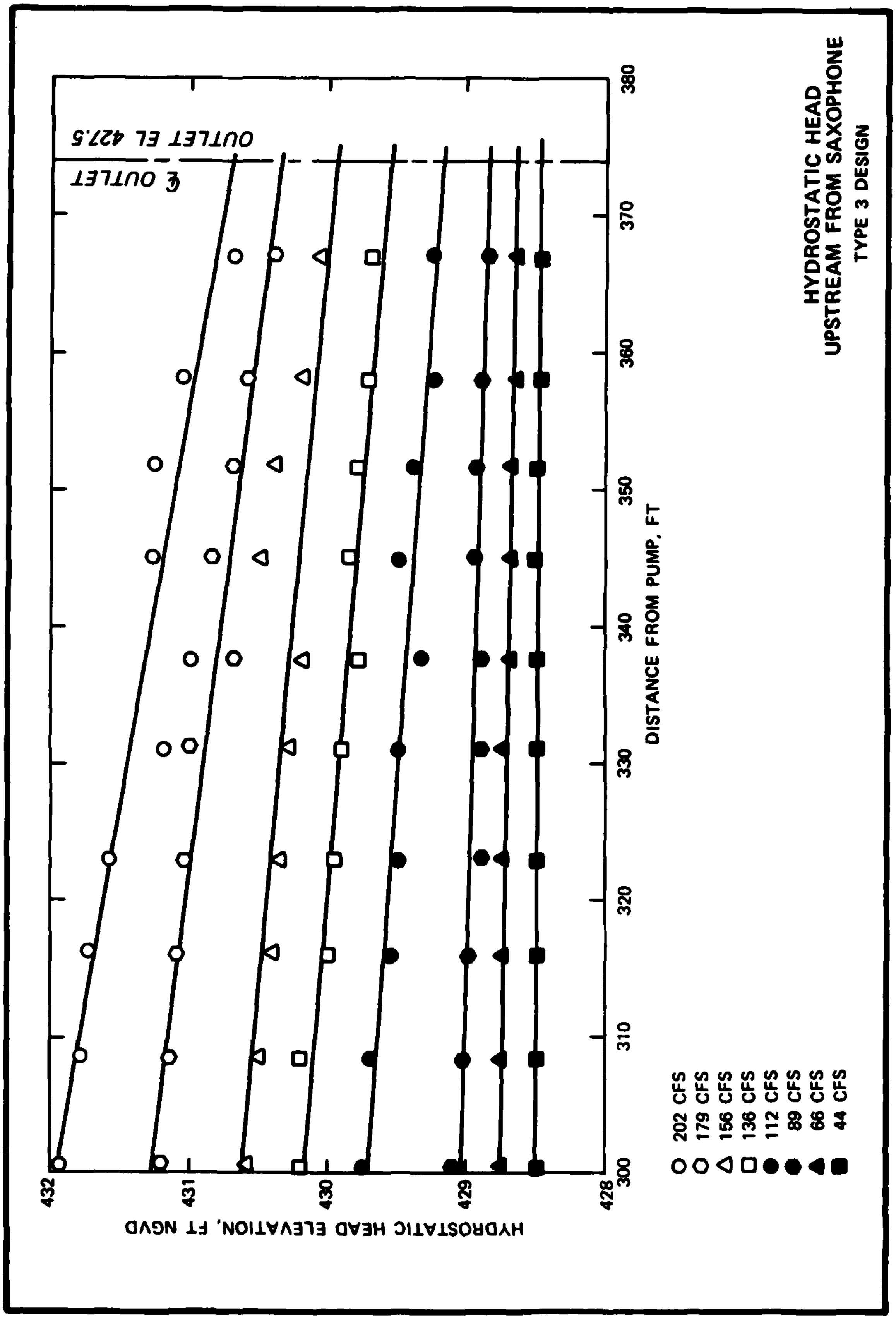
HYDRAULIC JUMP LOCATION

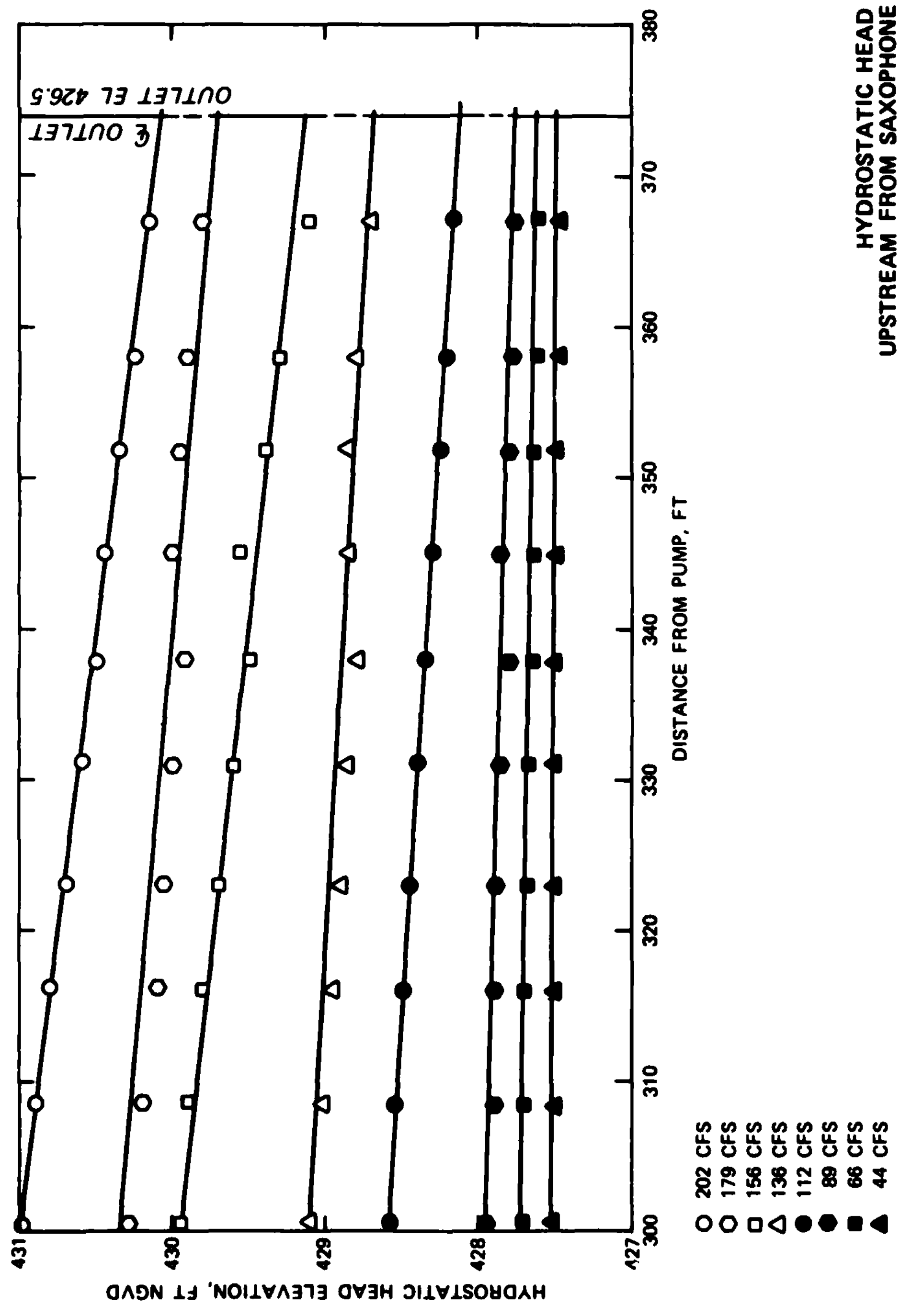


MEASURED HYDROSTATIC HEAD UPSTREAM OF SAXOPHONE OUTLET

TYPE 1 DESIGN

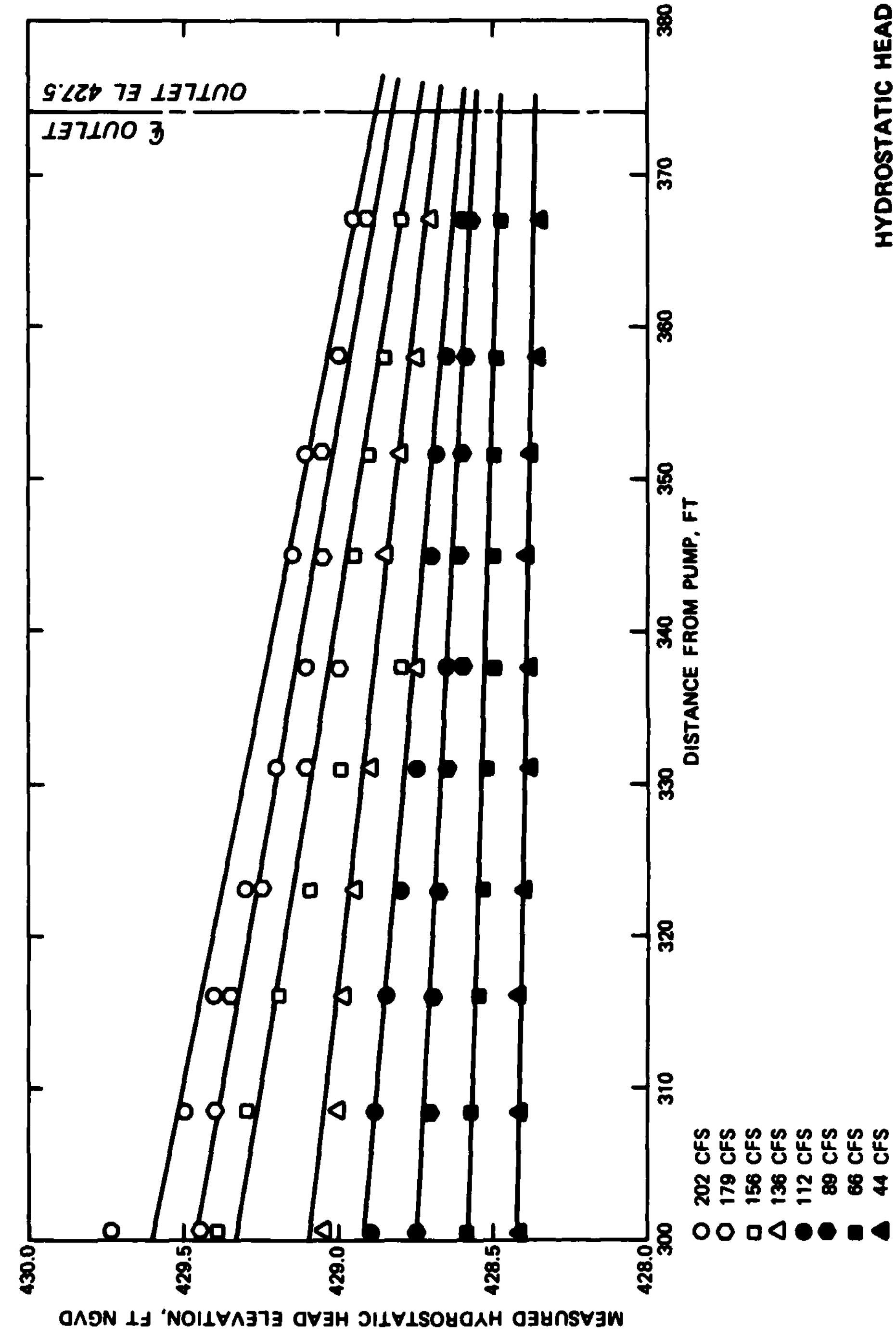
PLATE 4


HYDROSTATIC HEAD
UPSTREAM FROM SAXOPHONE
TYPE 3 DESIGN
HYDROSTATIC HEAD ELEVATION, FT NGVD
DISTANCE FROM PUMP, FT
℄ OUTLET
OUTLET EL 427.5
202 CFS
179 CFS
156 CFS
136 CFS
112 CFS
89 CFS
66 CFS
44 CFS
432
431
430
429
428
300
310
320
330
340
350
360
370
380

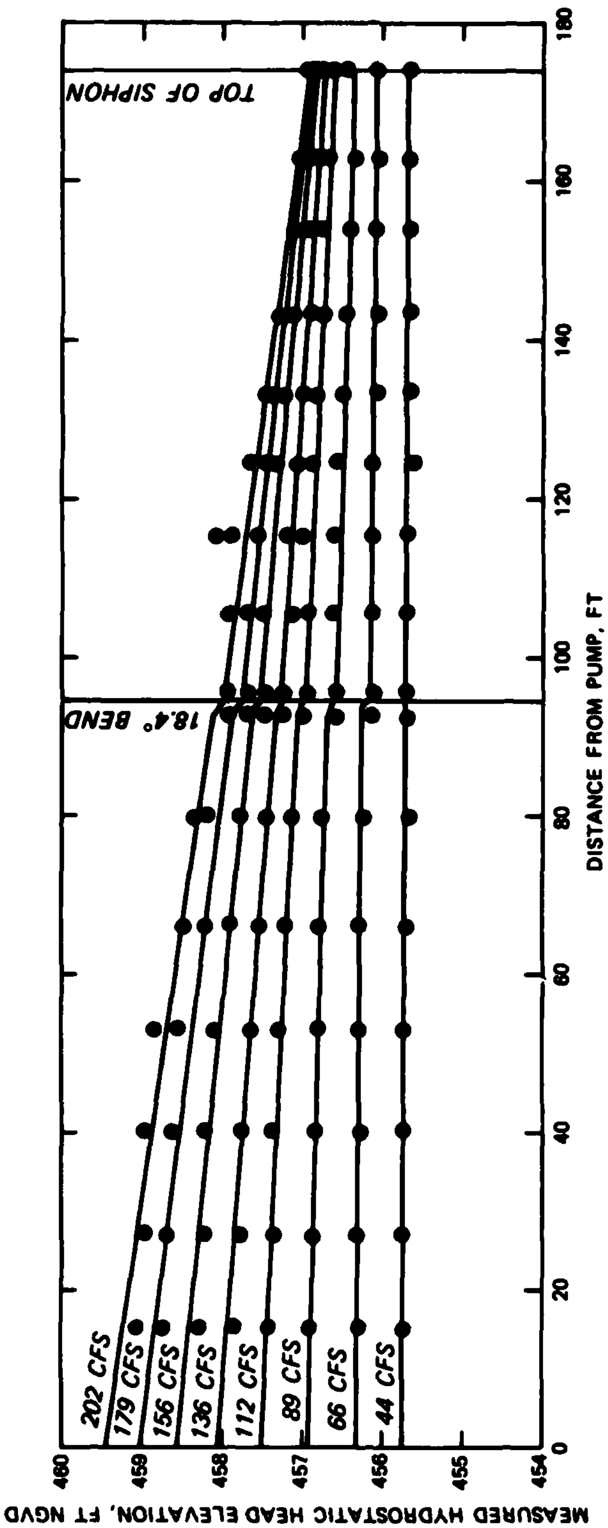


HYDROSTATIC HEAD
UPSTREAM FROM SAXOPHONE OUTLET
TYPE 4 DESIGN

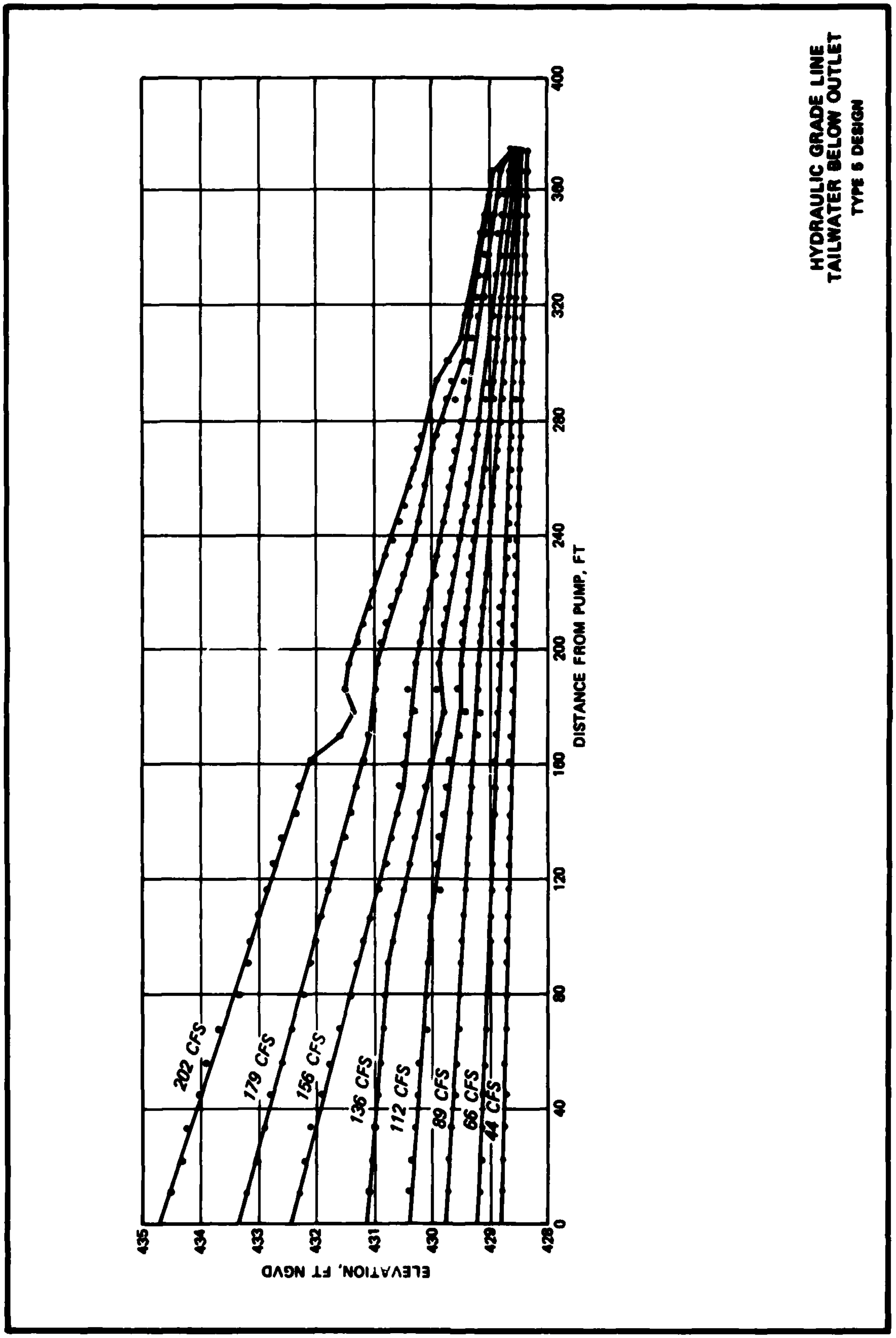
PLATE 6

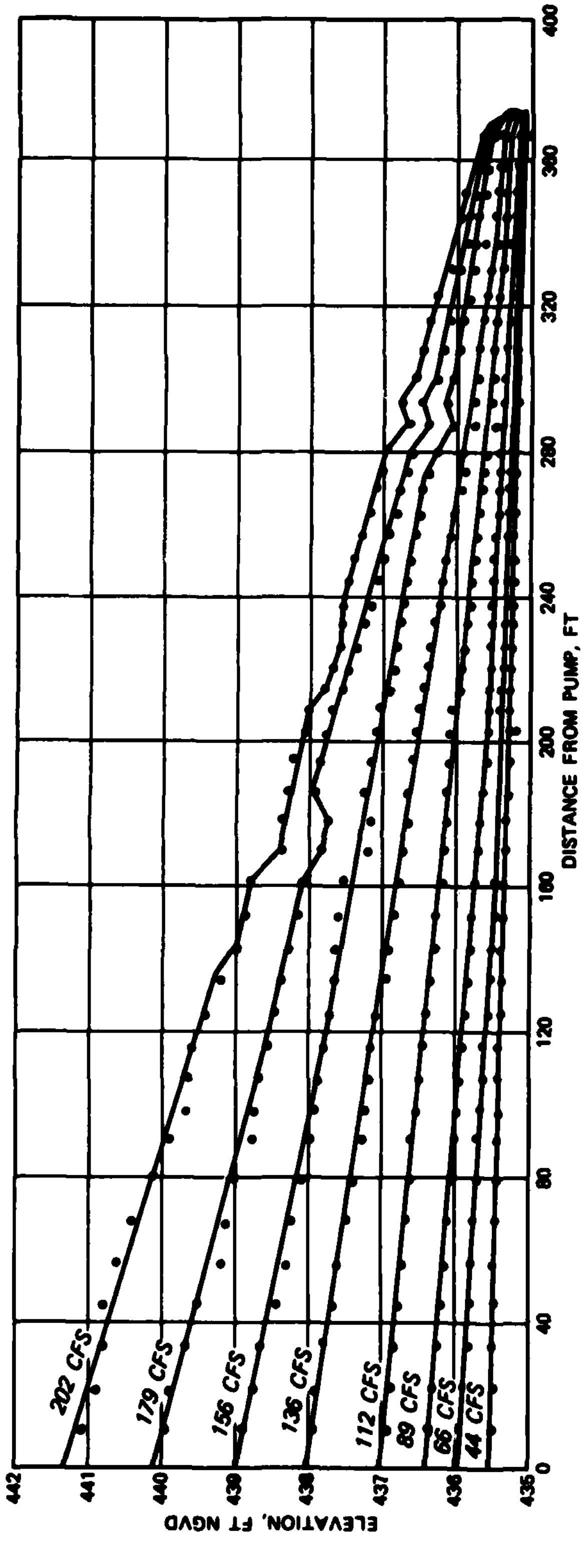


HYDROSTATIC HEAD
UPSTREAM FROM SAXOPHONE OUTLET
TYPE 5 DESIGN

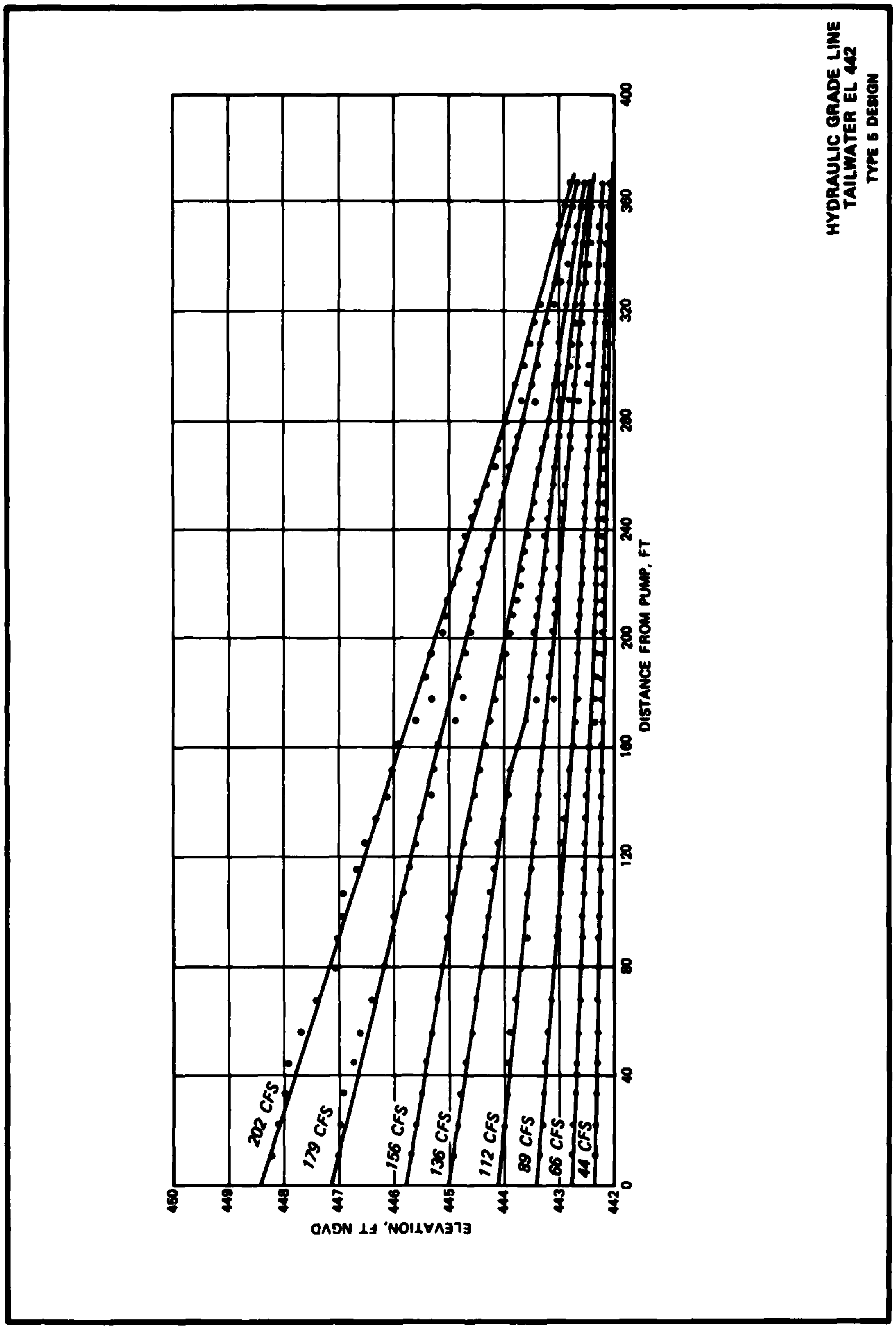


MEASURED HYDROSTATIC HEAD
AIR VENT AT CROWN OPEN
TYPE 1 DESIGN


HYDRAULIC GRADE LINE
TAILWATER BELOW OUTLET
TYPE 5 DESIGN
DISTANCE FROM PUMP, FT
ELEVATION, FT NGVD
0
40
80
120
160
200
240
280
320
360
400
428
429
430
431
432
433
434
435
202 CFS
179 CFS
156 CFS
136 CFS
112 CFS
89 CFS
66 CFS
44 CFS



HYDRAULIC GRADE LINE
TAILWATER EL 436
TYPE 5 DESIGN


HYDRAULIC GRADE LINE
TAILWATER EL 442
TYPE 5 DESIGN
ELEVATION, FT NGVD
DISTANCE FROM PUMP, FT
202 CFS
179 CFS
156 CFS
136 CFS
112 CFS
89 CFS
66 CFS
44 CFS
450
449
448
447
446
445
444
443
442
0
40
80
120
160
200
240
280
320
360
400

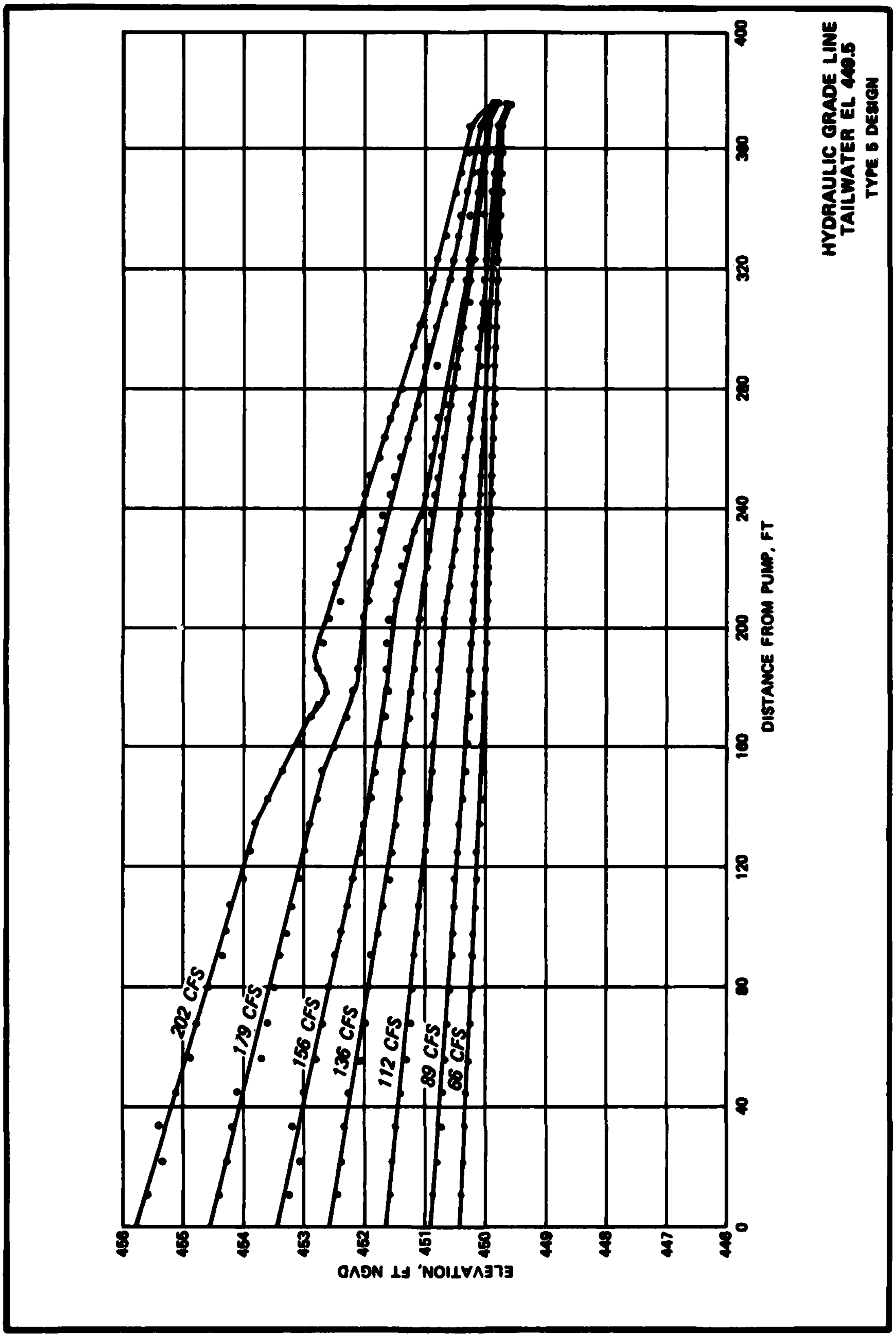
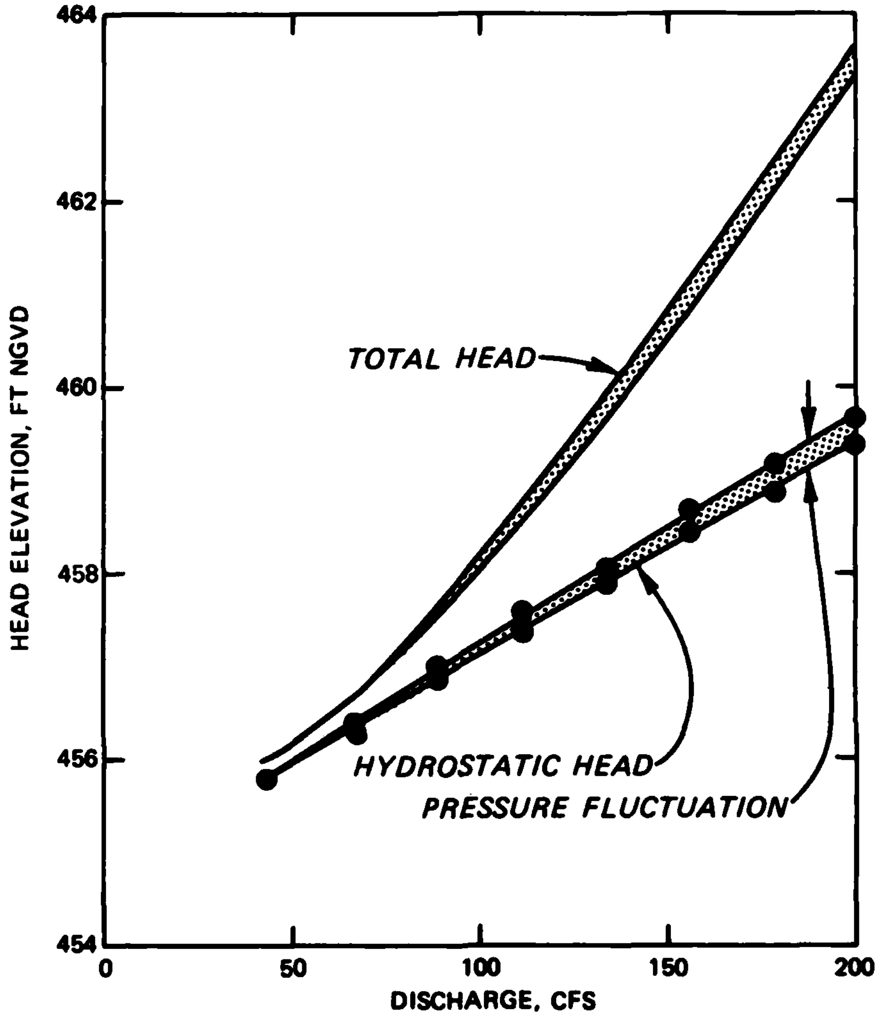
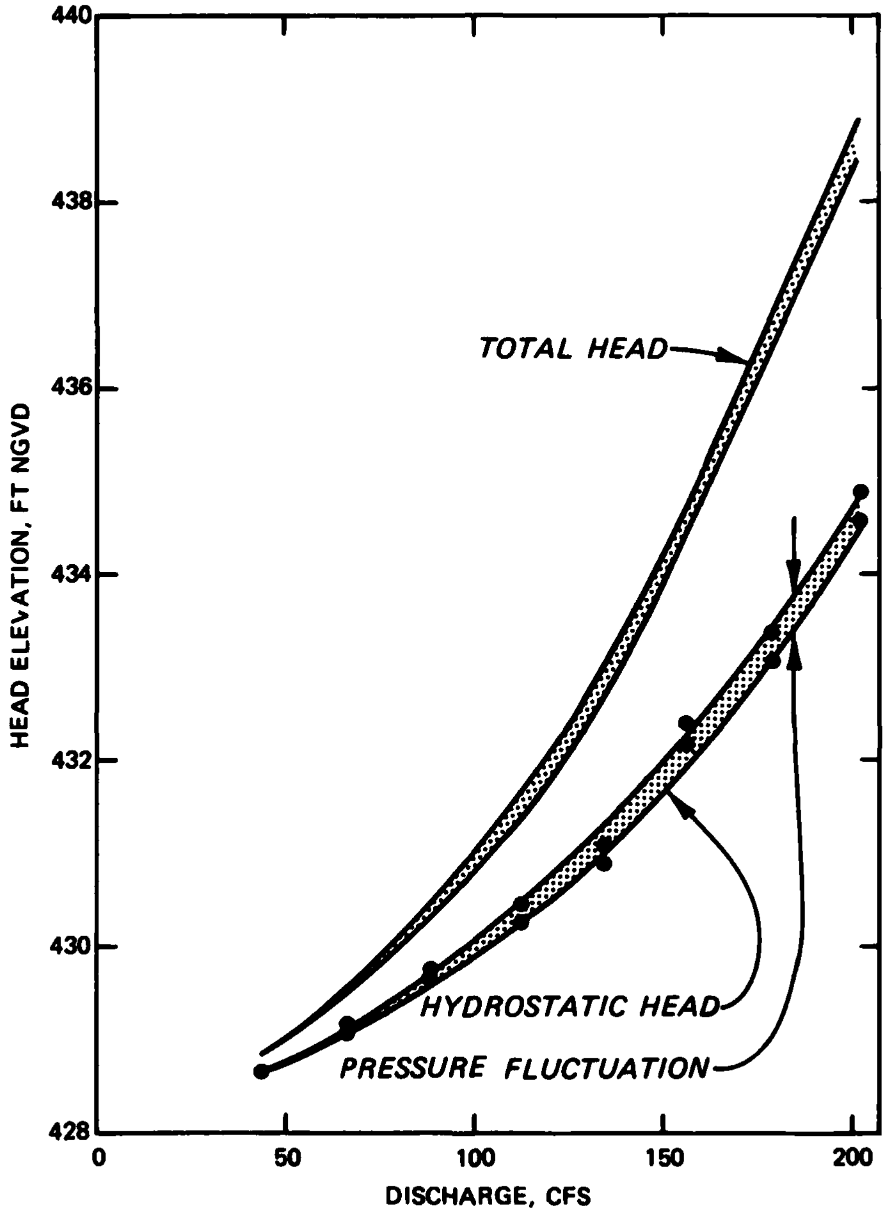

HYDRAULIC GRADE LINE
TAILWATER EL 449.5
TYPE 5 DESIGN
DISTANCE FROM PUMP, FT
ELEVATION, FT NGVD
202 CFS
179 CFS
156 CFS
136 CFS
112 CFS
89 CFS
66 CFS
0
40
80
120
160
200
240
280
320
360
400
456
455
454
453
452
451
450
449
448
447
446

PLATE 12

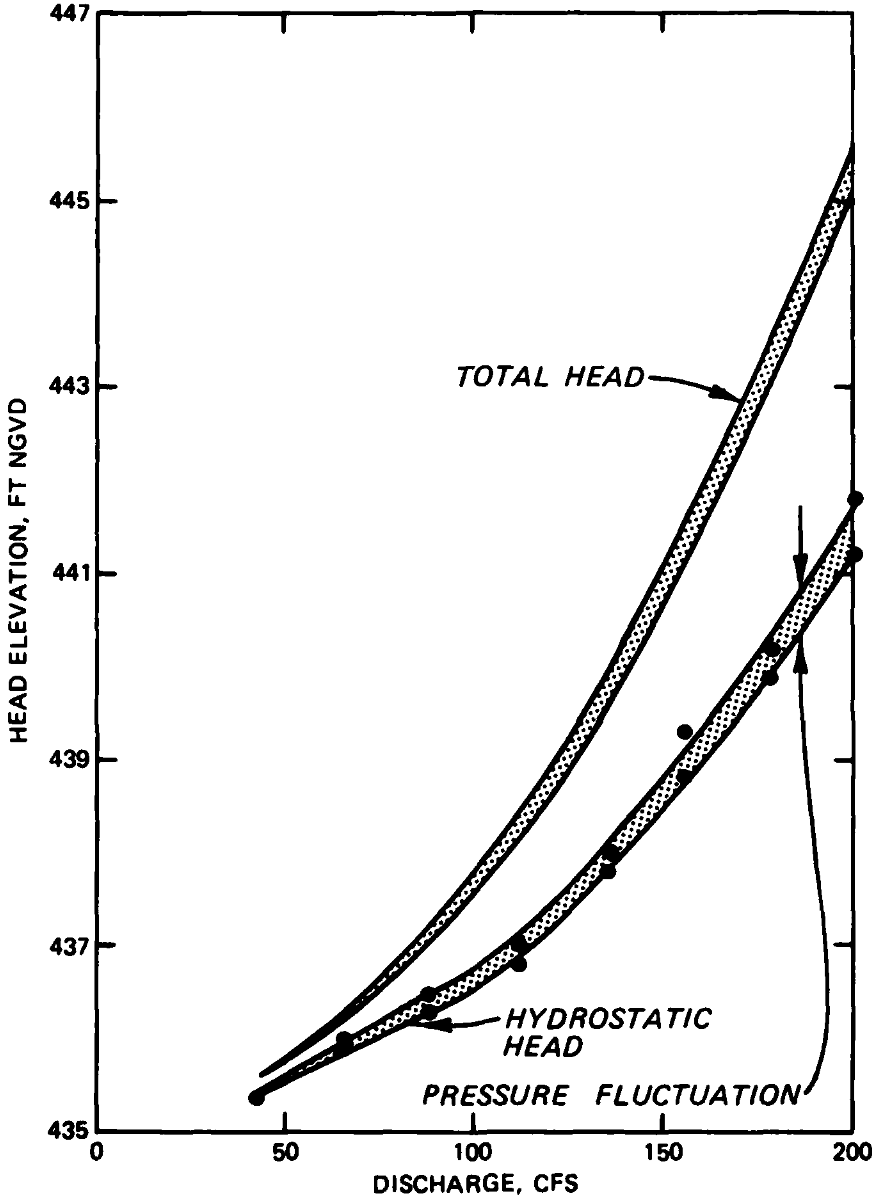


HEAD ELEVATION AT PUMP AT START OF PRIMING

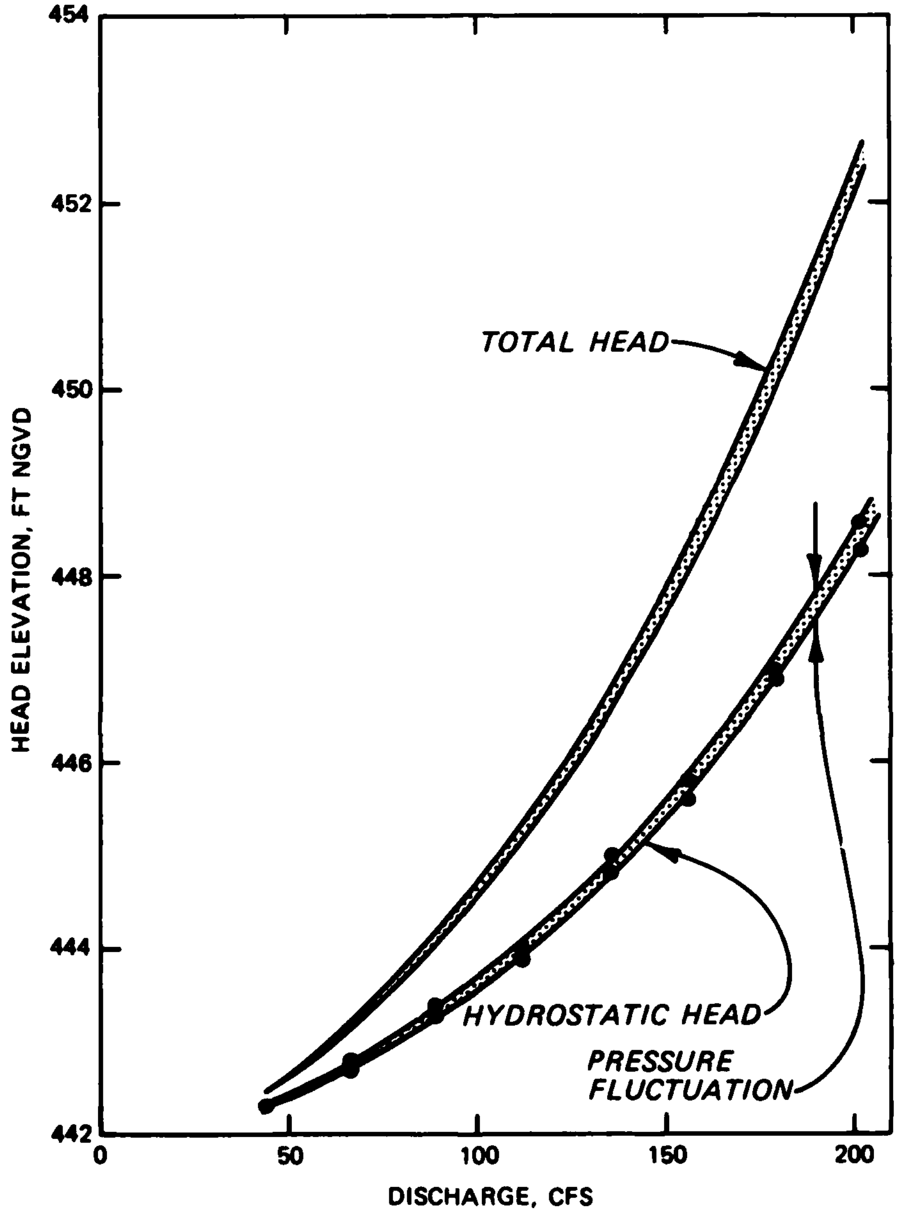
TYPE 1 DESIGN



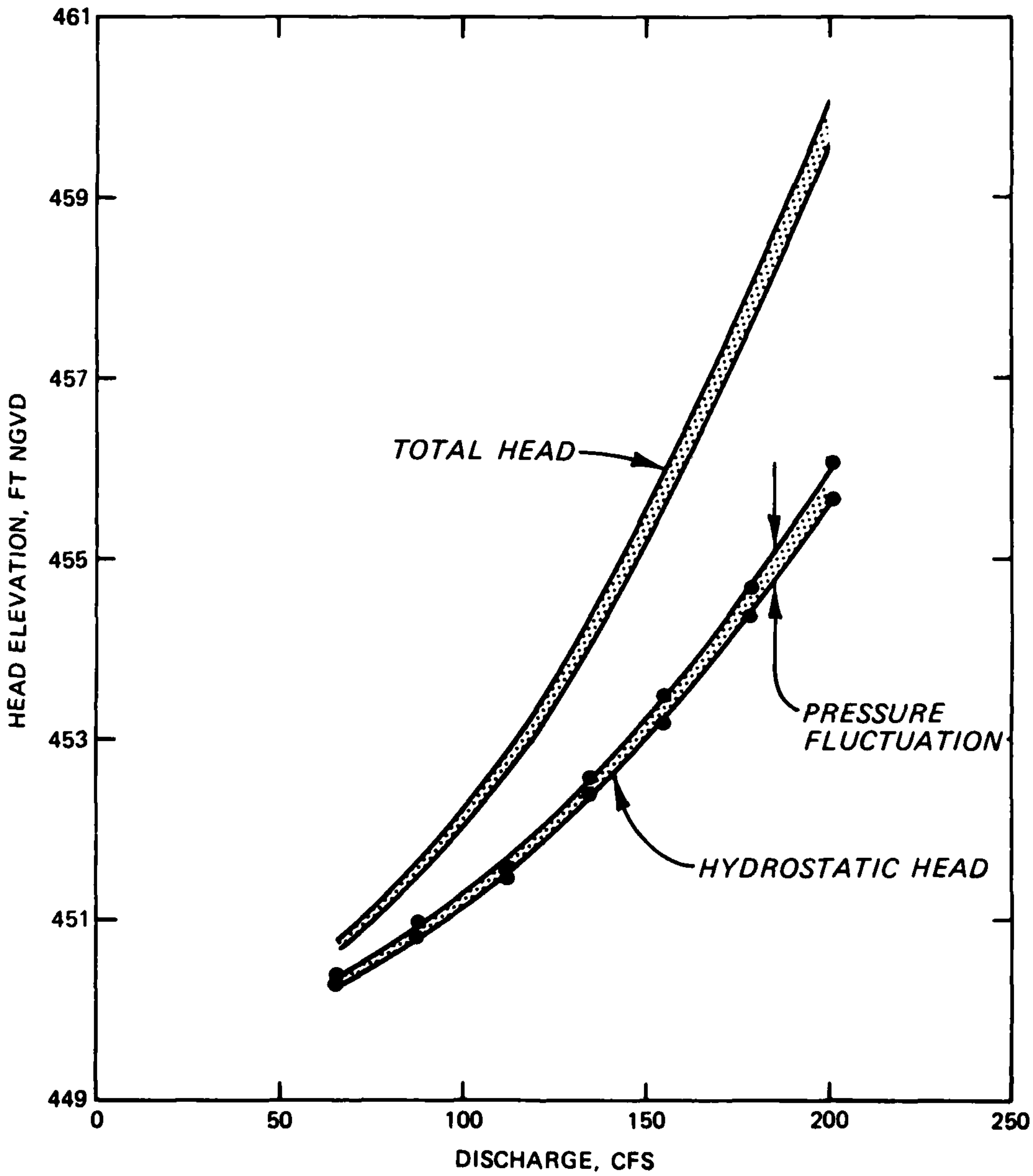
HEAD ELEVATIONS AT PUMP
SIPHON PRIMED
TAILWATER BELOW OUTLET
TYPE 5 DESIGN



HEAD ELEVATIONS AT PUMP
SIPHON PRIMED
TAILWATER EL 435
TYPE 5 DESIGN



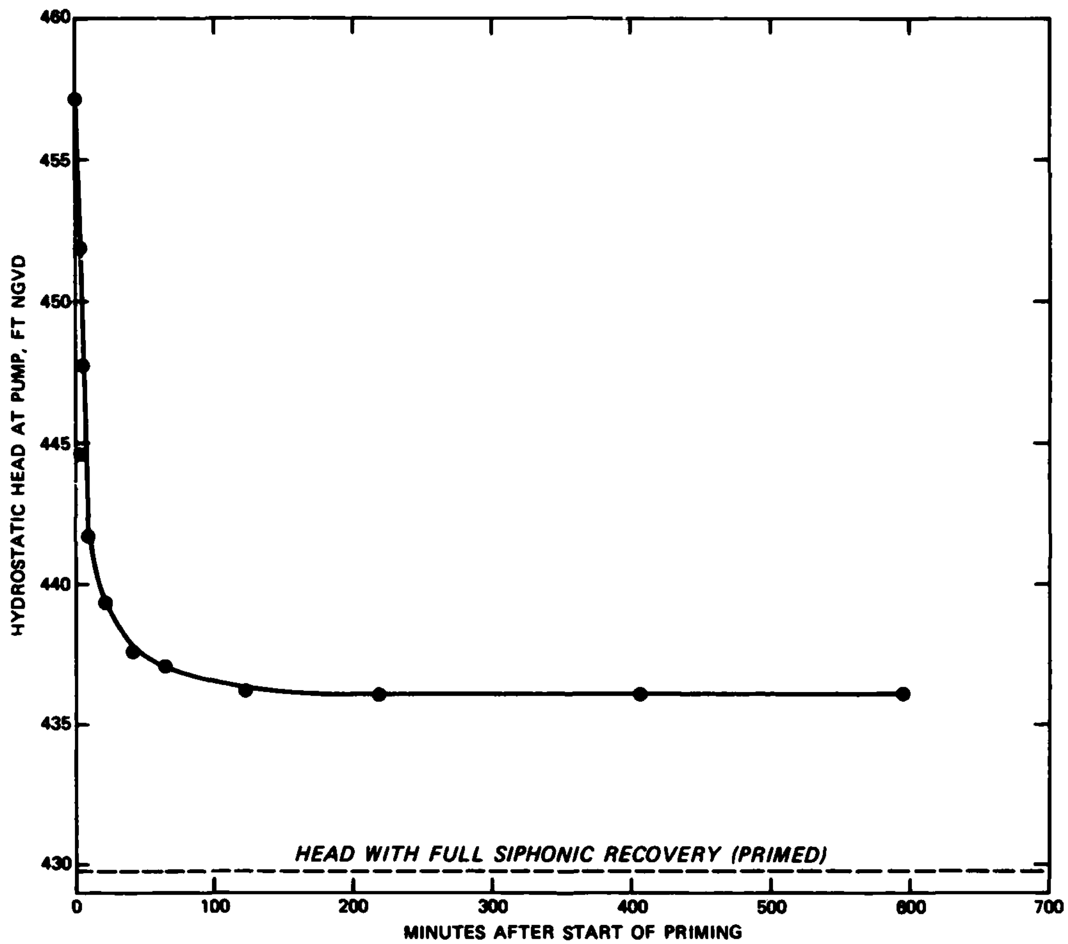
HEAD ELEVATIONS AT PUMP
SIPHON PRIMED
TAILWATER EL 442
TYPE 5 DESIGN



HEAD ELEVATIONS AT PUMP SIPHON PRIMED

TAILWATER EL 449.5

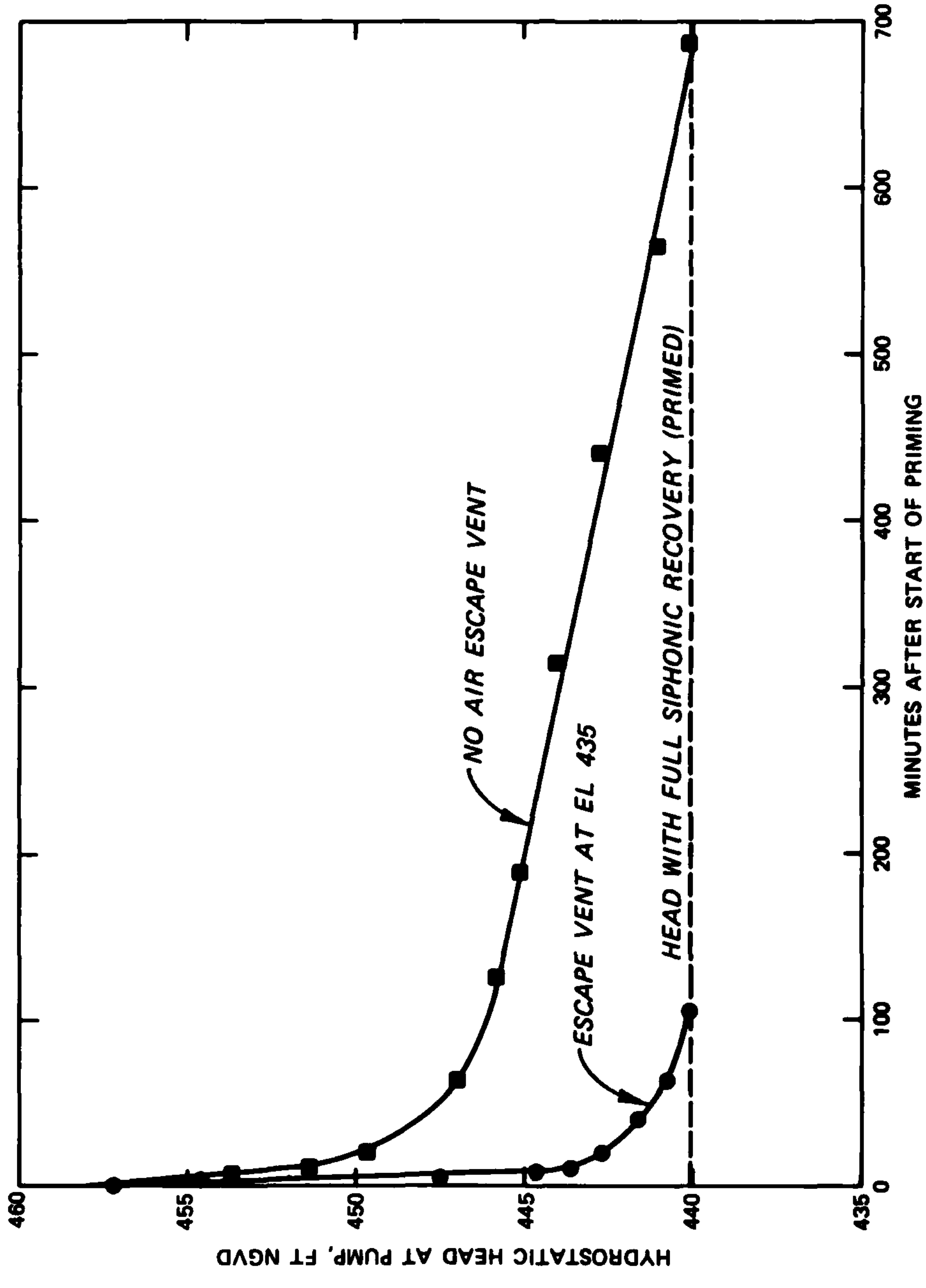
TYPE 5 DESIGN

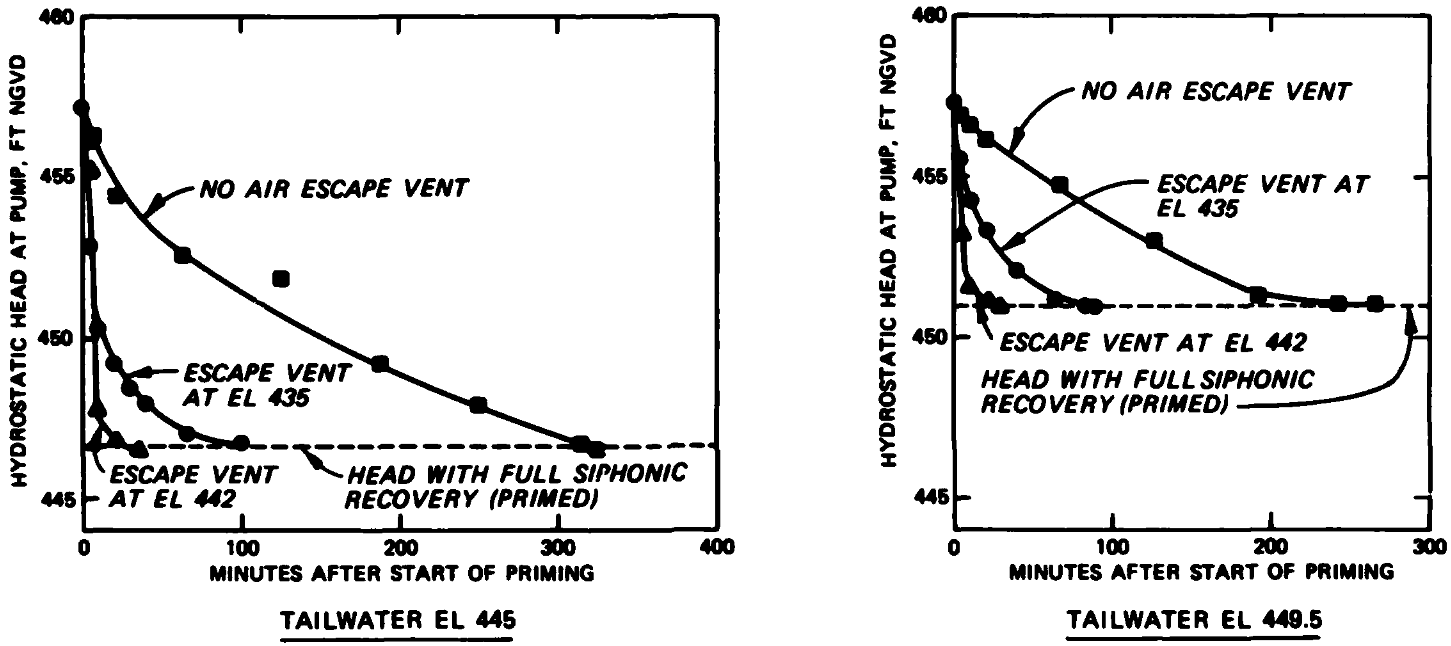


SIPHONIC HEAD RECOVERY
CONSTANT DISCHARGE 89 CFS
TAILWATER BELOW OUTLET

PLATE 18

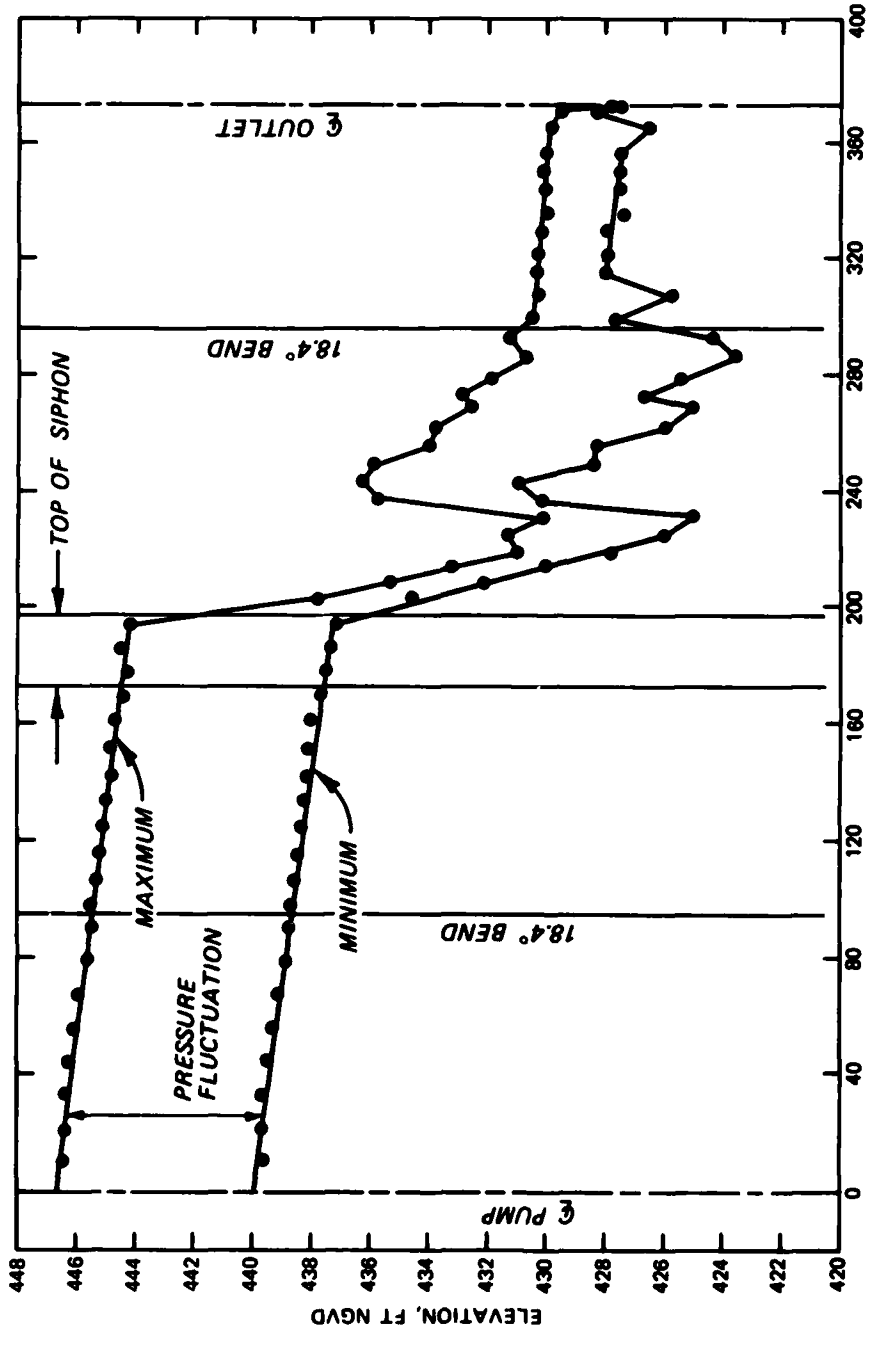
SIPHONIC HEAD RECOVERY
CONSTANT DISCHARGE 89 CFS
TAILWATER EL 438.5



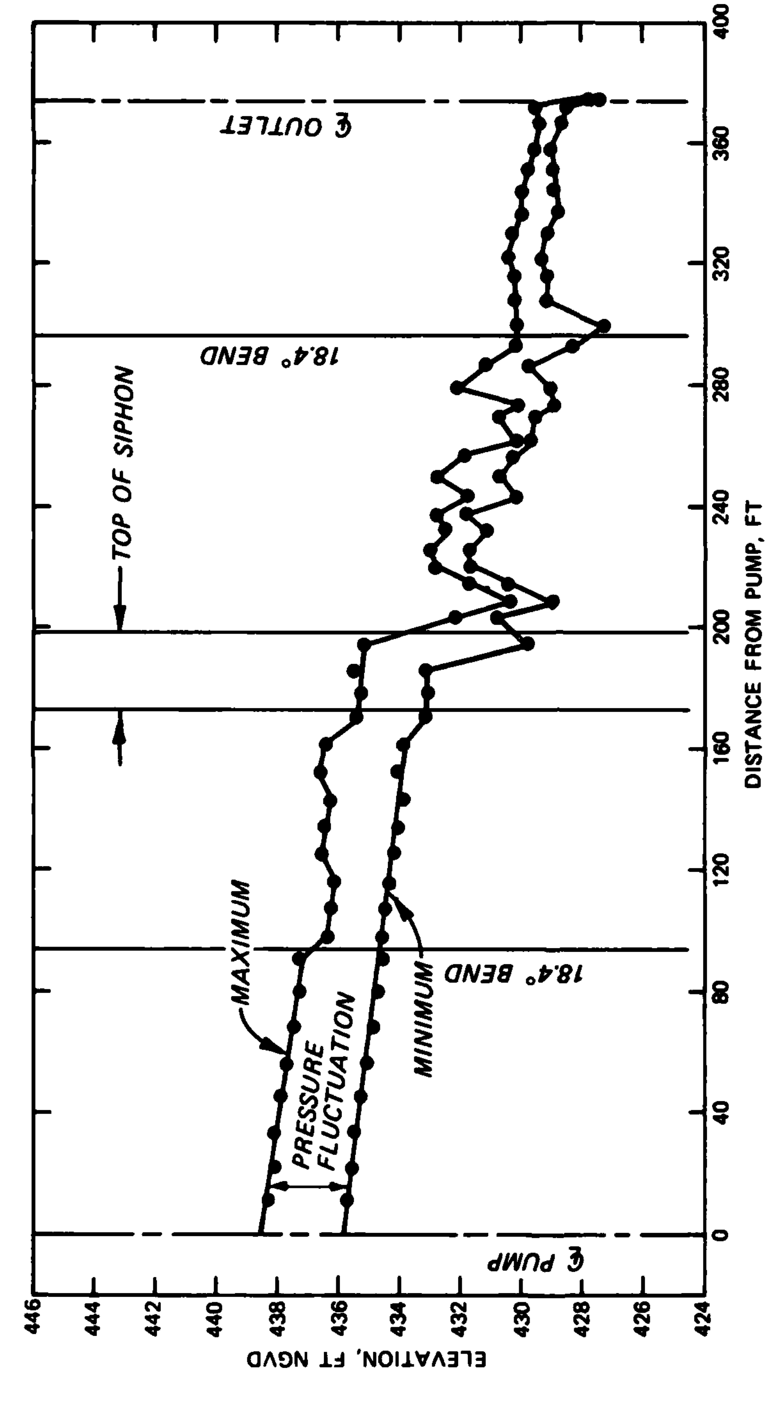


SIPHONIC HEAD RECOVERY

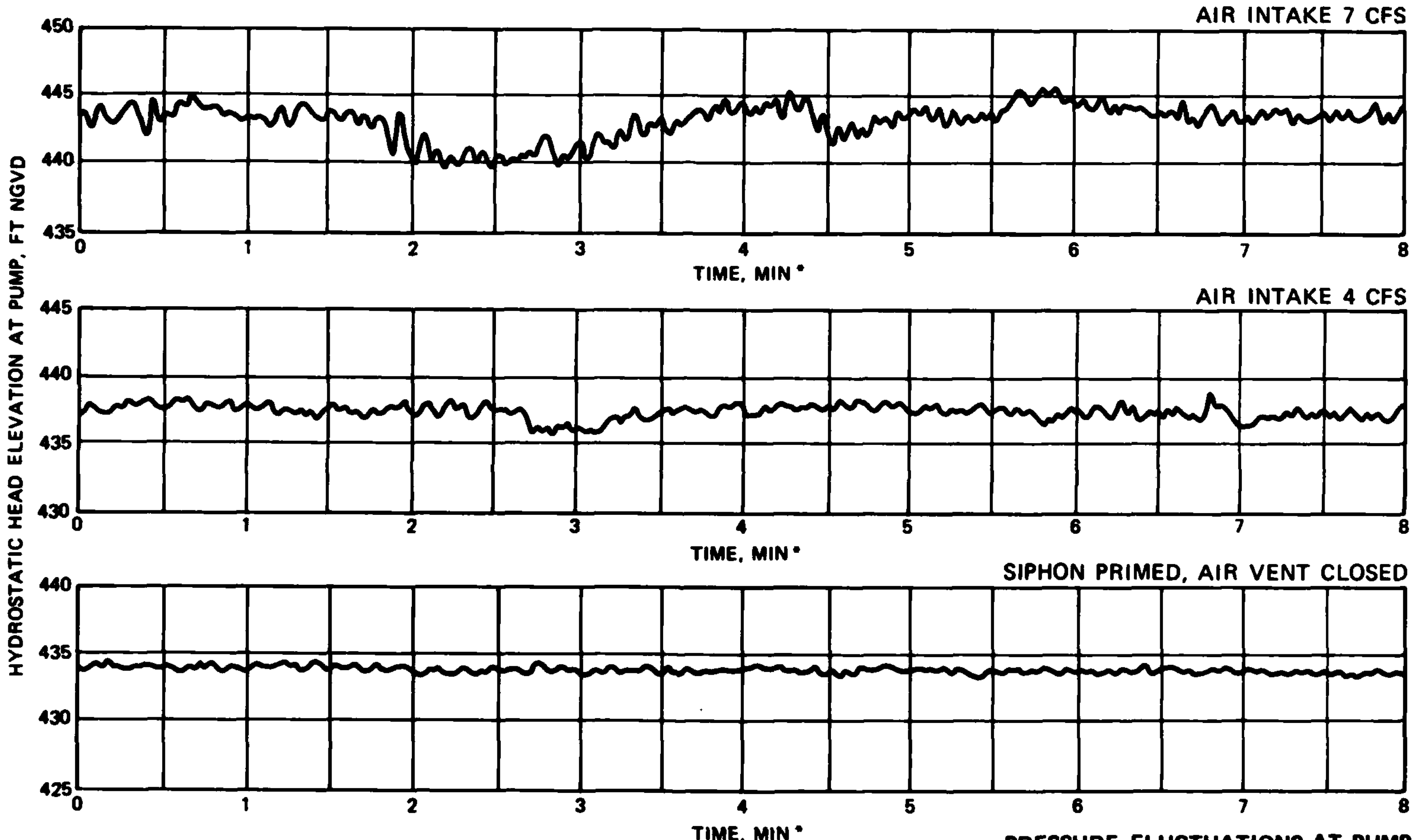
CONSTANT DISCHARGE 89 CFS
TAILWATER EL 445 AND 449.5



PRESSURE FLUCTUATIONS
SIPHONIC RECOVERY CONTROLLED BY AIR INTAKE
WATER DISCHARGE 168 CFS
TAILWATER BELOW OUTLET
TYPE 4 DESIGN OUTLET
AIR DISCHARGE 7 CFS

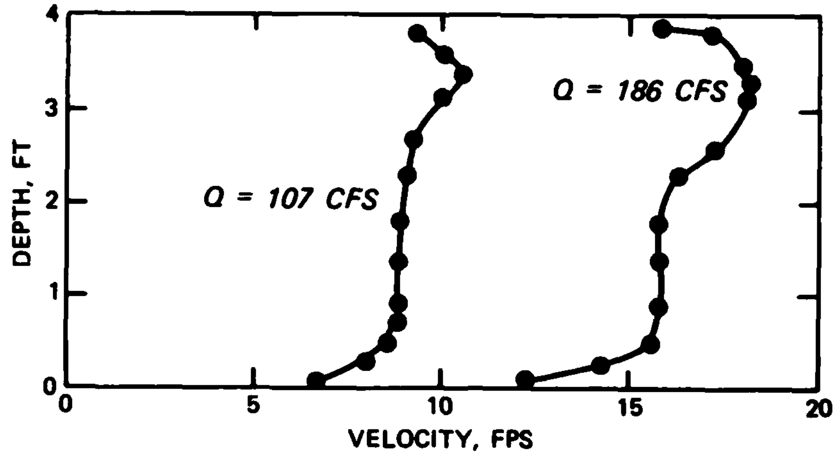


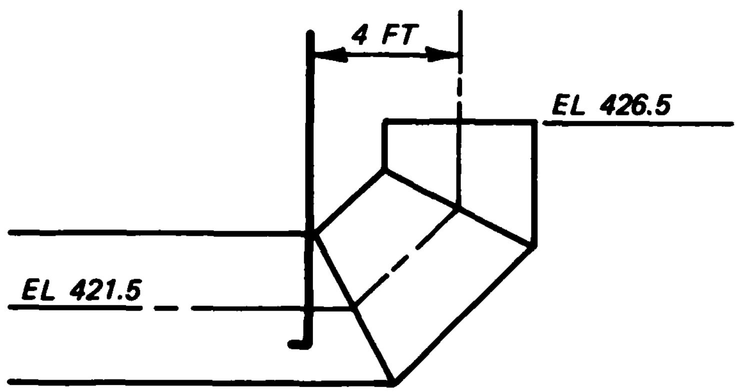
PRESSURE FLUCTUATIONS
SIPHONIC RECOVERY CONTROLLED
BY AIR INTAKE
WATER DISCHARGE 168 CFS
TAILWATER BELOW OUTLET
TYPE 4 DESIGN OUTLET
AIR DISCHARGE 4 CFS



PRESSURE FLUCTUATIONS AT PUMP
TAILWATER BELOW OUTLET
TYPE 4 DESIGN OUTLET
DISCHARGE 168 CFS

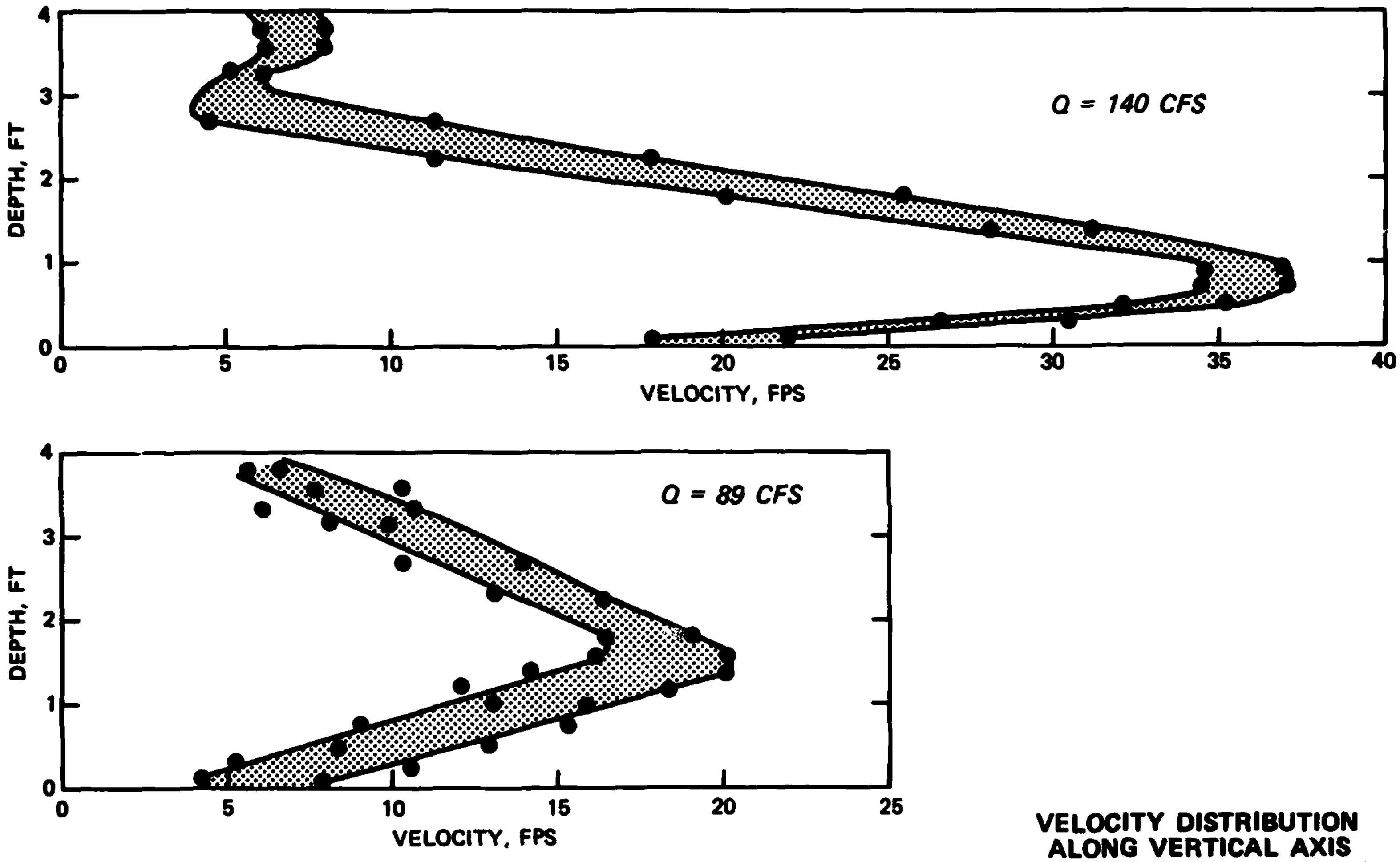
* RANDOM SAMPLE





LOCATION OF VELOCITY MEASUREMENTS

VELOCITY DISTRIBUTION ALONG VERTICAL AXIS 4 FT UPSTREAM FROM CENTER OF DISCHARGE PIPE OUTLET SIPHON PRIMED
TYPE 4 DESIGN



VELOCITY DISTRIBUTION
ALONG VERTICAL AXIS
4 FT UPSTREAM FROM CENTER OF
DISCHARGE PIPE OUTLET
AIR VENT OPEN
TYPE 4 DESIGN

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Copeland, Ronald R.
McGee Creek pumping station siphon, Pike County, Illinois : Hydraulic Model Investigation / by Ronald R. Copeland (Hydraulics Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. ; The Station ; Springfield, Va. ; available from NTIS, 1982.
36, [12] p., 25 p. of plates : ill. ; 27 cm. -- (Technical report ; HL-82-23)
Cover title.
"September 1982."
Final report.
"Prepared for U.S. Army Engineer District, St. Louis."
Bibliography: p. 35.

1. Hydraulic models. 2. McGee Creek Pumping Station (Ill.) 3. Pumping stations. 4. Siphons. I. United States. Army. Corps of Engineers. St. Louis District. II. U.S. Army Engineer Waterways Experiment Station. Hydraulics

Copeland, Ronald R.
McGee Creek pumping station siphon, Pike County : ... 1982.
(Card 2)

Laboratory. III. Title IV. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; HL-82-23.
TA7.W34 no.HL-82-23

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